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# **Boston Harbor Navigation Channel Improvement Project**

Field Data Collection Program Final Report

Michael W. Tubman

June 2007



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Final report

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**Abstract:** A field data collection program in Boston Harbor, MA, was conducted for the U.S. Army Engineer District, New England, during the late fall and winter of 2004/2005. The purpose of the program was to obtain data needed to validate a numerical hydrodynamic model (ADvanced CIRCulation (ADCIRC) model) of Boston Harbor and adjacent areas. The currents calculated by the verified model were input to a ship simulator used to assess the design of the Boston Harbor navigation improvement project.

A total of four water-level recorders and two acoustic profiling current meters were deployed on 10 November 2004. The water-level recorders were located adjacent to a bridge between Chelsea and East Boston in Boston's inner harbor, at the seaward end of Boston North Channel, at Gallops Island, and at the Hull Yacht Club in Allerton Harbor. The current meters were located at the seaward end of Boston North Channel and near the location where Boston's main navigation channel enters the inner harbor. Data from these instruments were supplemented by tide data from a National Oceanic and Atmospheric Administration (NOAA) tide gage in the inner harbor, and NOAA wind measurements at Logan Airport. In addition, daylight current transect surveys using a downward looking acoustic profiling current meter attached to a survey vessel were conducted on 11 November 2004 and 8 February 2005. Five transect survey lines across the main navigation channel were surveyed. All instrumentation was recovered on 7 and 8 February 2005.

Maximum-measured ebb tidal currents in the harbor were 0.9 to 3.84 ft/sec. Maximum-measured flood currents were 0.77 to 3.61 ft/sec. In general, the ebb currents were stronger than the flood currents. The data from the current meter deployed at the seaward end of Boston North Channel were analyzed to evaluate the importance of the wind-driven and tide-induced residual currents. The results of the analysis were that combined, these currents are small (5 to 22 percent of the ebb currents and 6 to 26 percent of the flood currents) compared to the maximum-measured tidal currents within the harbor. The tide-induced residual current at the seaward end of the navigation channel was estimated to be 0.07 ft/sec. The technical literature shows that tide-induced residual currents within the harbor, in the vicinity of the navigation channel, are stronger than they are at that location, with speeds of about 0.33 ft/sec.

The largest currents at the seaward end of the navigation channel resulting from the action of the wind during major storms were associated with outflow of the storm surge from within the harbor. The analyses showed that during a major storm in December 2004, the currents were 0.54 ft/sec toward 70 deg, and during one of the worst storms (in terms of wind speed) in recent history, which occurred in January 2005, they were 0.56 ft/sec toward 69 deg (both speeds include an estimated tide-induced residual vector of 0.07 ft/sec toward 90 deg). The maximum water-level range is defined as the largest change in elevation from high-water to the low-water immediately following, that was recorded at a gage location. The maximum water-level range includes wind effects, as well as the astronomical tide. The range was 13.9 ft at the bridge between Chelsea and East Boston, 13.5 ft at Gallops Island, 14.1 ft at the Hull Yacht Club, and 13.9 ft at the NOAA gage.

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## **Preface**

The field data collection program of Boston Harbor, MA, documented in this report was performed for the U.S. Army Engineer District, New England (CENAE). John H. Winkelman was the CENAE liaison during the study.

The program was conducted by the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL), from November 2004 to June 2005, under the direct supervision of Thomas W. Richardson, Director, CHL, Bruce A. Ebersole, Chief, Flood and Storm Protection Division, and William Birkemeier, Chief, Field Data Collection and Analysis Branch. The work was performed by John R. Bull, Christopher J. Callegan, John M. Kirklin, Thad C. Pratt, and Michael W. Tubman. This report was written by Mr. Tubman.

At the time of the study, COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

# 1 Introduction

## Purpose

A field data collection program in Boston Harbor, MA, was conducted for the U.S. Army Engineer District, New England (hereafter New England District), during the late fall and winter of 2004/2005. The purpose of the program was to obtain data needed to validate a numerical hydrodynamic model (ADvanced CIRCulation (ADCIRC) model) of Boston Harbor and adjacent areas. The currents calculated by the verified model were input to a ship simulator used to assess the design of the Boston Harbor navigation improvement project. The proposed effort (see the original Scope of Work (SOW) in Appendix A) was for water-level measurements at two locations, current and wind measurements, each at one location, for a 1- to 2-month period. In addition, transects of current measurements across the navigation channel were proposed for two spring tidal cycles.

During planning of the first field effort, it was realized that the field program could be improved. It was found that wind data are available from a meteorological station at Logan International Airport, and the proposed wind-measurement station was eliminated from the program. This made it possible to collect additional current and water-level data without exceeding the proposed budget. Two additional water-level recorders (for a total of four), and two current-meter moorings, instead of the one proposed, were deployed.

As specified in the SOW, the deliverables of the field data collection program are:

- Time series of water-level measurements and interpolation at all benchmarked locations in the harbor.
- Vectorized current velocity data from the transect data entered into a GIS database.
- Time series of currents at the current-meter mooring.
- Correlations between mooring and transect current data.
- Correlations between wind data and filtered mooring current data.
- Summary of wind statistics for the deployment period.
- Correlations between current and water-level data.

Funding for the program was provided by the New England District of the U.S. Army Corps of Engineers (Point of Contact (POC): John H. Winkelman, CENAE-EP-EW, telephone: 978-318-8615) to the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). Two previous reports on the field data collection program have been sent to the New England District. One report was submitted after the instruments were deployed and the first transect current survey was conducted on 10 and 11 November 2004, and the second was submitted after the instruments were recovered and the second current survey was conducted on 7 and 8 February 2005. This is the final report for the project. The work was conducted by ERDC personnel Thad C. Pratt (POC: ERDC-CHL-HF-HM, telephone: 601-634-2959), John Bull, Chris Callegan, John Kirklin, and Michael W. Tubman.

## Study Area

Boston Harbor and adjacent areas, and the areas of the navigation channel improvement project are shown in Figure 1. Typical navigationally significant currents in the harbor are primarily the result of tidal forcing. The semi-diurnal  $M_2$  tidal component, which has a 12.42-hr period, is the most navigationally significant current. However, the  $M_2$  tidal currents are modulated by the  $S_2$  and  $N_2$  components, resulting in spring tidal currents that are 33 percent stronger than average currents. The spring tidal currents occur every 15 days. There is relatively little freshwater input to the harbor, and density-driven currents are not significant in terms of their effect on ship navigation. Water-level differences over the harbor (at any one time) are small in the absence of wind. Without wind-driven effects, water levels in the harbor are controlled by the astronomical tides, and the magnitudes and timing of their variations are nearly the same over the entire harbor.

The instrument mooring locations and the location of the wind station at Logan Airport are shown in Figure 2.

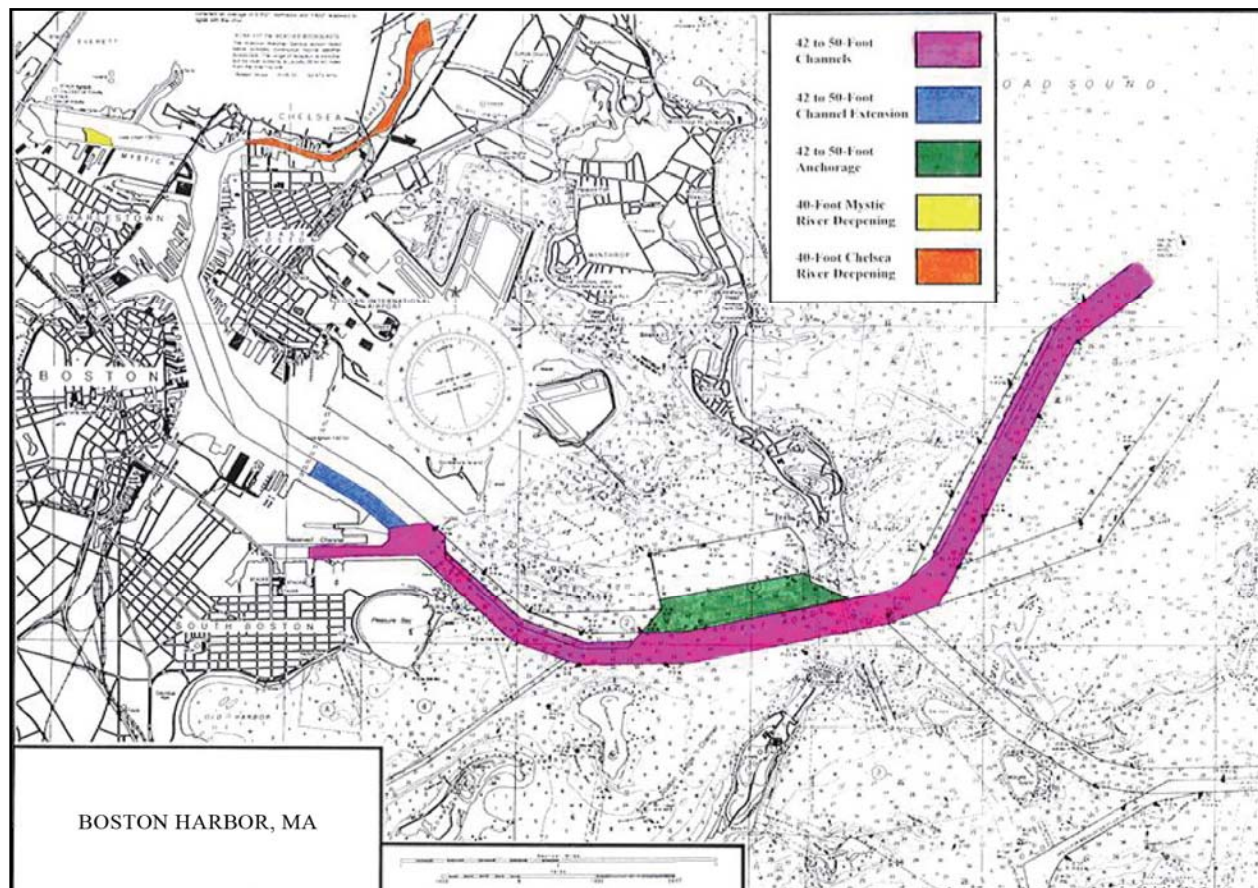


Figure 1. Boston Harbor and adjacent areas, and proposed channel deepening project.

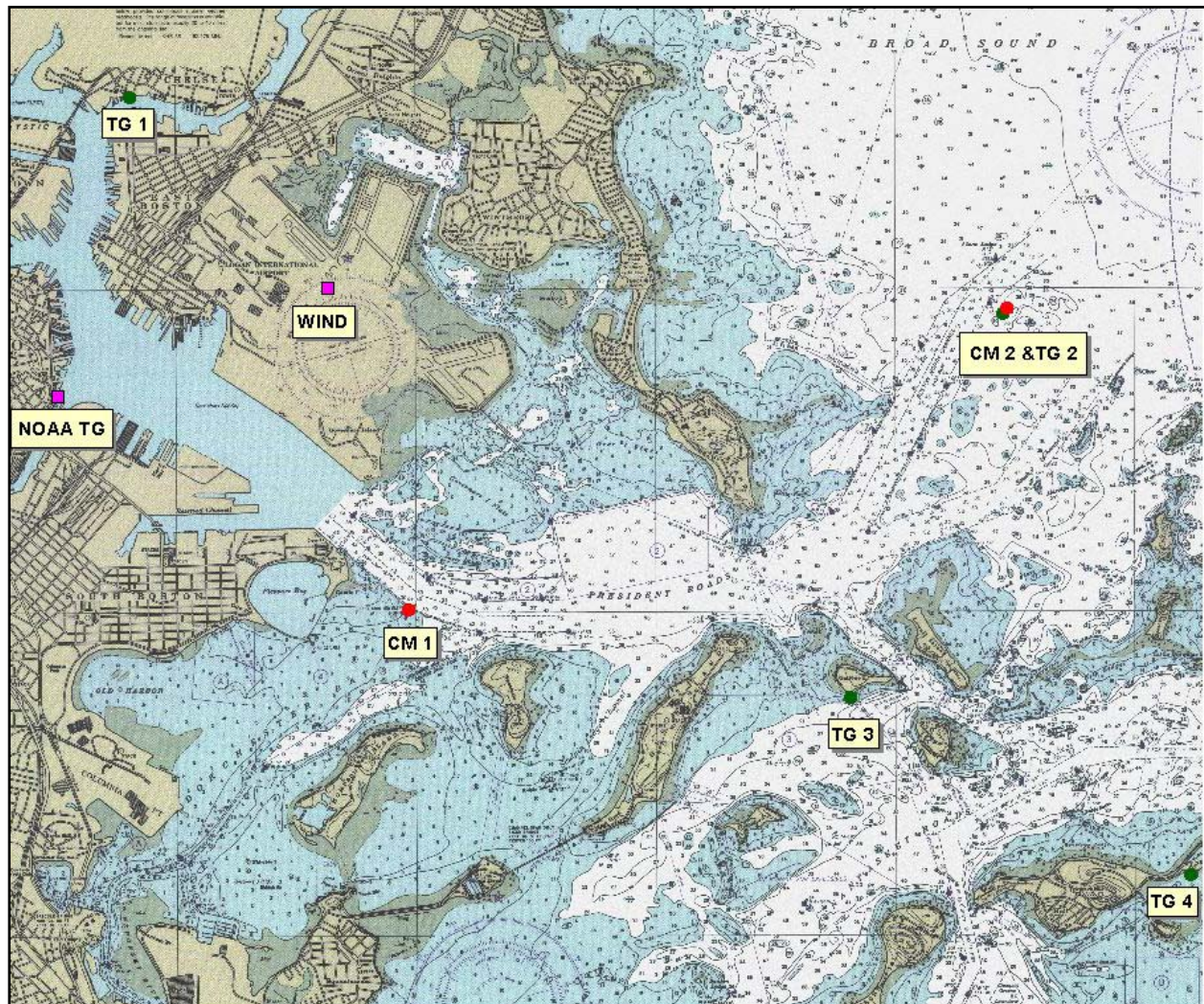


Figure 2. Locations of ERDC instrumentation (water-level recorders TG 1, TG 2, TG 3, TG 4 and current meters CM 1 and CM 2), NOAA tide gage (NOAA TG), and NOAA wind station (WIND).

## **2 Approach**

### **Design of Data Collection Program**

The National Oceanographic and Atmospheric Administration (NOAA) maintains a tide-measuring station in Boston's inner harbor. This station is referenced to a vertical datum. To verify ADCIRC, time series water elevation changes referenced to the record mean, as opposed to a verified datum, are adequate. Thus, the approach was to supplement the data from the NOAA station with water-level data from the four ERDC gages that were not surveyed to an established vertical datum.

Current information for the ship simulator studies was needed along the navigation channel. Producing this information was ADCIRC's primary role, and the focus of the field data collection program was to obtain current data for verification of the model along the channel. Therefore, two current transect surveys were undertaken at different locations along the navigation channel over two tidal cycles. For the purposes of the study, the strongest currents were thought to be the most significant, and the program plan was to make these surveys during spring tides. The importance of wind-driven currents was expected to be greatest near the seaward end of the navigation channel, which is basically in open-ocean waters. To record wind-driven currents, a mooring was deployed in this area. Wind measurements needed to correlate the wind-driven currents with the wind velocity were to come from the NOAA station at Logan Airport. Tidal asymmetry in the harbor can potentially result in residual tidal currents. To measure tidal currents in the vicinity of the navigation channel, a second current meter mooring was deployed near the entrance to the inner harbor.

### **Instrumentation**

Water-level measurements were made using Coastal Leasing Microtides systems. The Microtides is a self-contained, internally recording, microprocessor controlled system (Figure 3). The instrument determines the elevation of the water column above it by measuring the pressure. A Foxboro Pressure Sensor having an accuracy of 0.1 percent of full scale is used to make these measurements. The 30-psia systems that were deployed have an elevation accuracy of approximately 0.07 ft of seawater.

Before deployment, the water-level gages were programmed to record a measurement every second for 1 min, and record the average pressure over the 1-min interval. These water-level (pressure) measurements were repeated every 6 min. A short bench-test run was made, and the measured pressures were compared to atmospheric pressure.



Figure 3. Microtides self-contained, internally recording, microprocessor controlled, water-level gage.

The water-level recorders are well suited to the Boston Harbor environment. They were deployed well below the surface (approximately 6 ft) so that they were not visible from the surface, even at low tide. This helped avoid interference with them in this heavily populated area, and it kept them below a level where ice could damage them. The pressure sensors recorded water-level changes even during times when extensive ice cover was present in the harbor.

The two current meters that were placed in bottom moorings (Figures 4 and 5), and the current meter used to perform the tidal-current survey, are acoustic profiling systems. An acoustic profiling current meter transmits sound bursts into the water column that are scattered back to the instrument by particulate matter suspended in the flowing water. The

current meter “listens” for the returning signals and assigns depths to the received signals based on speed of sound and the time-after-transmit that the signals are received. The current speeds at those depths are determined on the basis of the change in frequency caused by the moving particles. This change in frequency is called Doppler shift. The bottom-moored current meters transmit their signals up toward the surface, whereas the survey current meter is mounted to the side of a survey vessel (Figure 6) and transmits its signals down toward the bottom as the vessel navigates along the survey line.



Figure 4. RDI ADCP and water-level gage mounted in mooring frame that was deployed near seaward end of navigation channel.

The survey acoustic current meter was a 1,200 kHz broadband Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments, Inc. (RDI). During data collection, the ADCP is capable of measuring vessel velocity, water velocity, water temperature, and bottom bathymetry. The measurement of the velocity of the vessel over the bottom allows the current velocity data to be corrected for the movement of the survey vessel. The current meter near the seaward end of the navigation channel (the Boston North Channel) was also an RDI 1,200 kHz ADCP. For that instrument when in a mooring, the manufacture specifies accuracies of

+/- 0.00656 ft/sec (0.2 cm/sec) for current speed and +/- 2 deg for current direction. The current meter deployed near the inner harbor was a 1,500 kHz Acoustic Doppler Profiler (ADP) manufactured by SonTek. For that instrument SonTek specifies accuracies of +/- 0.0164 ft/sec (0.5 cm/sec) for speed and +/- 2 deg for direction when the current meter is in a mooring.

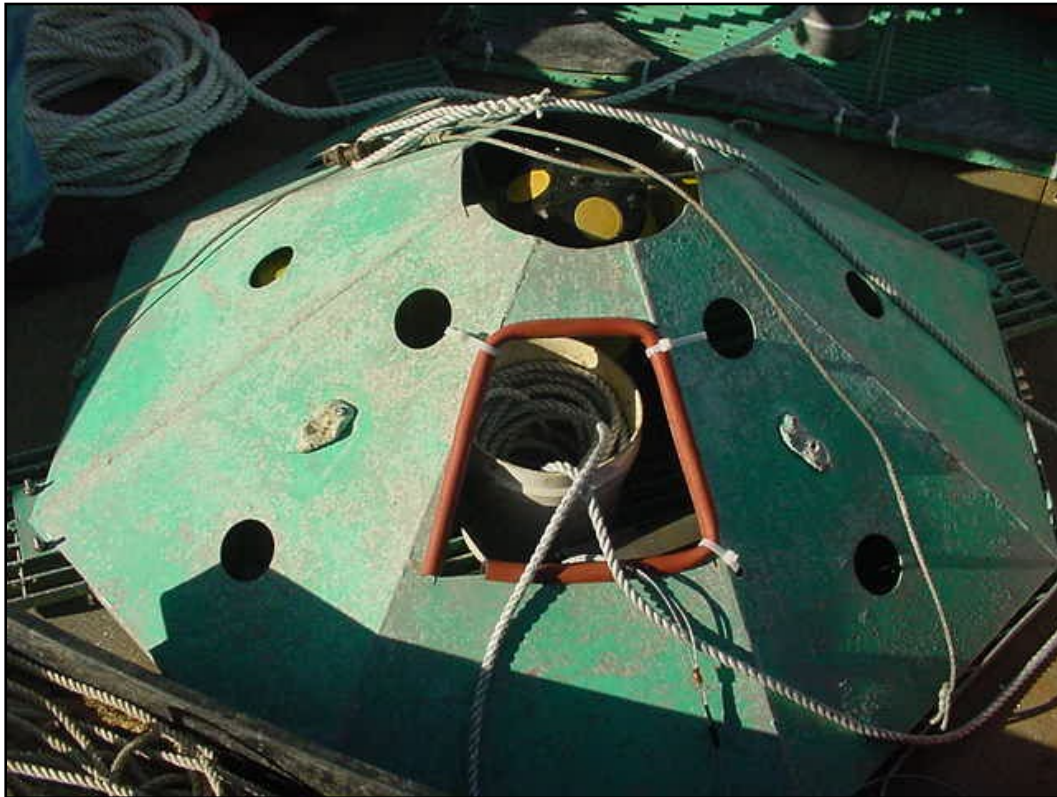


Figure 5. SonTek ADP mounted in mooring frame that was deployed near entrance to inner harbor.

The moored instruments were powered by batteries and recorded data internally. The survey instrument was externally powered and transmitted data over a cable to a computer onboard the survey vessel.

Before deployment, a program called BBTEST was run on a computer connected to the RDI current meter that was to be placed in the mooring. The program runs a series of diagnostic tests that establish that the ADCP is working properly and within specifications. To set the ADCP for deployment, the internally stored commands that the ADCP would use when started were displayed, reviewed, and changed where needed. The ADCP was set to average 170 pings, transmitted at the rate of approximately one every 0.7 sec, every 15 min, and recorded data in

1.641 ft (50 cm) vertical bins. According to RDI, this reduces the short-term random error of the acoustic measurements to near the long-term system bias of 0.007 ft/sec (standard deviation). A 120-sec averaging period was adopted to average out the wave-induced velocities.



Figure 6. Typical mounting for current transect ADCP on side of survey vessel.

The SonTek ADP used for the mooring near the entrance to the inner harbor does not have a diagnostic program. However, the compass operation was checked as recommended by SonTek, and a short bench-test run was made to verify operation of the system. As with the RDI current meter, the internal commands were displayed, reviewed, and changed where needed. The ADP transmitted nine pings per second, and was set to average the measurements from the pings over a 120-sec interval (again, to average out the wave-induced velocities) every 15 min. Data were recorded in 0.984 ft (30 cm) vertical bins. According to SonTek, this results in a standard deviation in the random error of the acoustic measurements of about 0.05 ft/sec.

The fact that the acoustic current meters can be mounted on the bottom, out of the way of vessel traffic, and can record the vertical current profile from that position means they are particularly well suited for harbor deployments. Care was taken not to deploy these meters at locations where large ships might be able to damage them in high sea states; locations were selected so that water was deep enough that boat traffic could not affect them.

Just prior to beginning the transect current surveys, a magnetic deviation correction was made by navigating pairs of back-and-forth lines along fixed headings and determining the differences between the bottom-track output headings (determined by the system compass) and the headings from GPS (true direction). The compass calibrations were verified by driving the survey vessel in a circle, starting and ending at the same spot. The bottom-track data also showed that the vessel had completed the circle and returned to the same point.

## **Mooring and Instrument Deployments**

With the exception of the water-level gage that was mounted on the current meter mooring frame deployed near the seaward end of the navigation channel (Figures 2 and 4), each gage was placed on a horizontal pedestal that was welded at a 90-deg angle to one end of an 8-ft-long aluminum angle iron (Figure 7). The gage was then strapped to the angle iron. Each gage was deployed by bolting the end of the angle iron opposite the gage to a wooden piling. A water-level recorder dedicated to recording atmospheric pressure was placed on land in Hull, MA. The atmospheric pressure measurements were made so that atmospheric effects on changing the water level could be removed from the water-level data.

The current meter deployed near the entrance to the inner harbor was placed next to a navigation channel marker (Figure 8) at a depth of approximately 15 ft mean low water (MLW). The other current meter was deployed near the seaward end of Boston North Channel at a depth of approximately 35 ft mean sea level (MSL). The exact location for this mooring deployment was selected primarily based on markers in the vicinity that showed fishing trawling lanes, as it was crucial to avoid trawling activity that could damage the instrumentation. Both moorings had sloped metal structures around them to help deflect anchors and other objects that might snag them. They also both had pop-up buoys (Figure 9) that released following activation by an acoustic signal from the surface. The buoys were held close to the bottom during the deployment. When released, they brought lines to the surface that were used to recover the moorings.



Figure 7. Water-level gage mounted on angle iron.



Figure 8. Navigation channel marker next to current meter deployed near entrance to inner harbor.



Figure 9. Deployment of pop-up buoy attached to mooring near seaward end of navigation channel.

The instrument deployments and recoveries were accomplished using the 35-ft fiberglass research vessel *Sakonnet*, based in Hull, MA (Figure 10). The *Sakonnet* has a 2,000-lb, 12-ft-high hydraulic A-frame that was used for deployment and recovery operations (Figure 11).

The *Sakonnet* was also used to conduct the current transect surveys. Waves were a problem for the surveys. In rough conditions, the movement of the ADCP can be such that it will lose track of the bottom and be unable to determine the speed of the survey vessel over the bottom. Vessel speed is an important measurement essential to obtaining good quality data. Certain transect lines that were planned to be run, were not, because the waves along them were too high. The waves that were encountered also required deviating from the ideal survey direction (which is perpendicular to the flow) for some lines, to more oblique angles. The survey lines are shown in Figure 12.



Figure 10. Research vessel *Sakonnet* based in Hull, MA, used for all operations.



Figure 11. A-frame on *Sakonnet* used to deploy current-meter moorings.

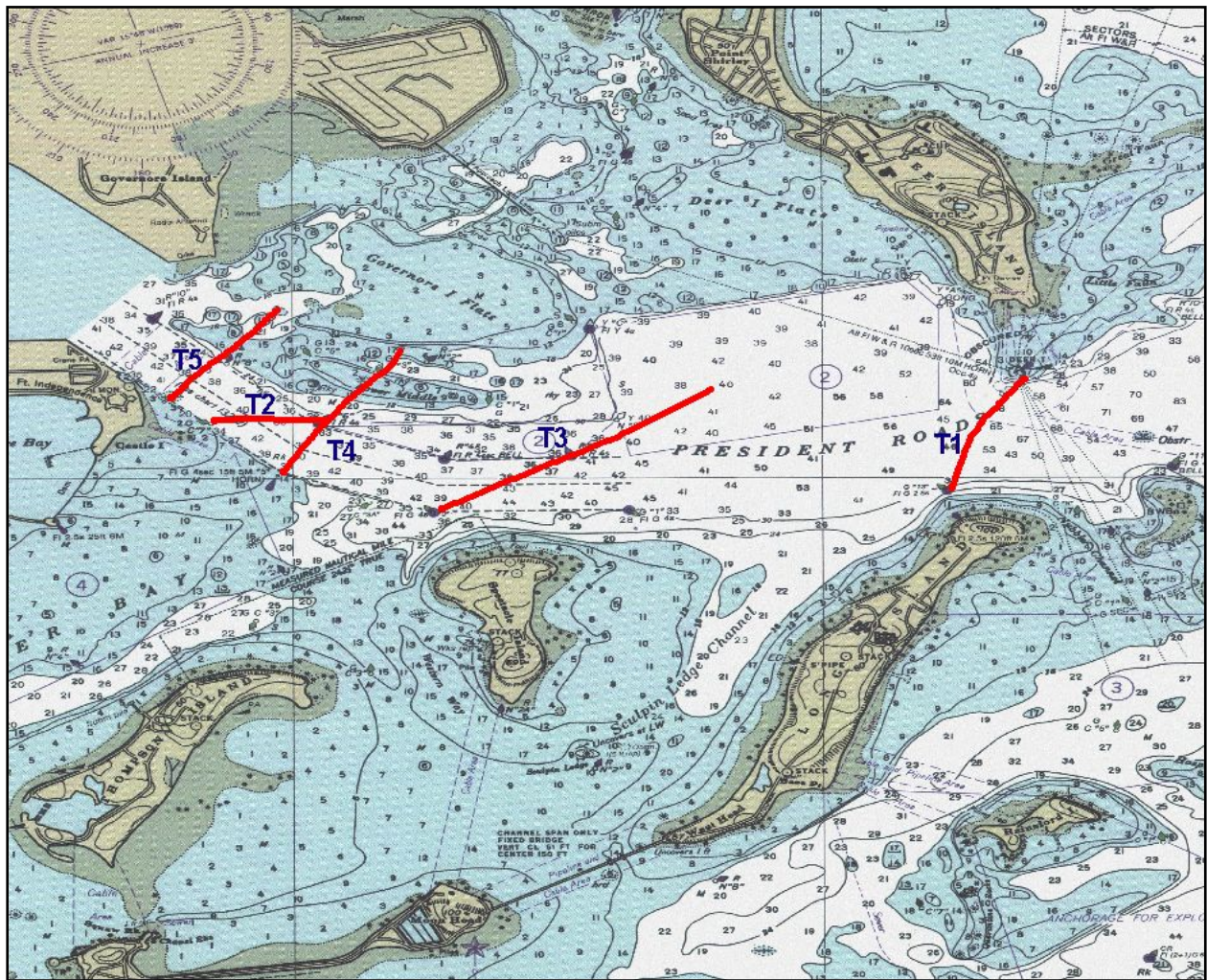


Figure 12. Current transect survey lines.

### **3 Chronology of Events**

#### **Preparations, Field and Post-Retrieval Activities**

The first field effort was conducted from 8 to 12 November 2004. Instruments were deployed and the first current transect survey was conducted. The instruments were recovered and the second current transect survey was conducted during the 6 to 9 February 2005 effort. Detailed chronologies of the program during these times are listed in Tables 1 and 2.

#### **Discussion**

CHL responded quickly after receiving funding to begin the program on 5 November 2004. All instrumentation was deployed 5 days later on 10 November. The SOW called for 1 to 2 months of data collection. However, 3 months of data were collected, primarily because one of the worst storms in the area in 50 years occurred on 23 January 2005. The winter storm resulted in the harbor freezing and made operations impossible until the week beginning 8 February when there were both favorable wave conditions and an open passage to the survey area.

After returning from the instrument deployment and first current transect survey on 12 November 2004, a report of the field activities and a preliminary analysis of the current transect data was prepared and transmitted to the New England District approximately 2 weeks later. The recovered instrumentation at the end of the project was returned to CHL on 10 February 2005 and processing of the data from the moored instrumentation was completed by the middle of April. The ADCIRC modeling effort was preformed by the New England District with assistance from CHL personnel, and the requested data from the field collection program were provided for the modeling effort in May. A report on the second current transect survey and instrument retrieval was sent to the New England District in June 2005.

Table 1. Summary of activities for first field effort, 3-12 November 2004.

Date	Time (local)	Activities
11/3-11/5	Day	Planning, arranging logistics, instrument preparation, packing equipment.
11/7-11/8	Day	Kirklin and Bull transported equipment to Boston in truck. Pratt and Tubman flew to Boston, MA, on 11/8.
11/9	Day	Mobilized survey vessel, started tide gages and current meters, purchased supplies, prepared ADCP mount for <i>Sakonnet</i> .
	1445	Deployed TG4 on pier at Hull Yacht Club.
11/10	1015	Deployed TG2 and CM2.
	1055	Deployed CM1.
	1245	Deployed TG1.
	1351	Deployed TG3.
	1430-1645	Mounted ADCP on survey vessel and attempted calibration (ferrous metal in mount prevented calibration).
	Night	Replaced ferrous metal in ADCP mount.
11/11	0430	Kirklin and Bull started back to Vicksburg, MS, in truck.
	0600	Calibrated ADCP.
	0630-1600	Current transect survey along T3, T4, and T5.
	1630-1830	Demobilized survey vessel.
11/12	Day	Pratt and Tubman returned to Vicksburg, MS, by plane, Kirklin and Bull arrived in Vicksburg in truck.

Table 2. Summary of activities for second field effort, 5-10 February 2005.

Date	Time (local)	Activities
2/5-2/6	Day	Kirklin, Bull, and Callegan transported equipment to Boston, MA, in truck.
2/7	Morning	Mounted ADCP on survey vessel and calibrated it.
	1355	Recovered TG1.
	1527	Recovered CM1.
	1646	Recovered CM2.
2/8	0800-1500	Current transect survey along T1, T2, and T3.
	1616	Recovered TG3.
	1645	Recovered TG4.
	Evening	Demobilized survey vessel.
2/9-2/10	Day	Returned equipment to Vicksburg, MS, in truck.

An unknown problem with the current meter deployed near the entrance to the inner harbor (CM1) resulted in it not recording data. The current meter deployed at the seaward end of the navigation channel (CM2) recorded data during the entire deployment period, which included the time of the winter storm on 23 January 2005.

All of ERDC's water-level gages functioned throughout the storm and through the period where large areas of the harbor were ice covered. As a result of the requirement to stay out of trawling lanes, the water depth where the water-level recorder attached to the mooring on the seaward end of the navigation channel was deployed (TG2) ended up being approximately 5 ft deeper at high tide than the maximum range of the water-level gage. Thus, the tidal variations in water level were accurately recorded over about 60 percent of the total tidal range (missing a portion of high tide).

The NOAA tide gage in Boston's inner harbor failed at the beginning of the 23 January 2005 storm, and did not become operational again until near the beginning of 5 February 2005. The NOAA anemometer at Logan Airport provided data for the entire program with only a few invalid measurements.

## 4 Data Processing and Analysis

### Processing Steps

Verified NOAA wind data from Logan Airport were downloaded from their Web site (<http://cdo.ncdc.noaa.gov/CDO/dataproduct>) as an ASCII file, and time series plots were made using in-house software. The data from the Microtides water-level recorders were down-loaded from the systems using software supplied by the manufacturer. The data were checked to verify that the atmospheric pressures recorded before and after deployment were correct. Using the atmospheric pressure, values recorded by the water-level recorder kept on land in Hull, MA, the atmospheric pressures were subtracted from the field data, and the pressures were converted to water-level values using a representative density of sea water (1.025 times the density of fresh water). The depths recorded just after deployment, and just prior to recovery, were then checked to verify that they agreed with the field observations at those times. The water levels were then referenced to the record means and stored in ASCII files.

The acoustic current meter that did not record data was manufactured by SonTek and there was no need to process data from it. The other moored current meter was the RDI ADCP deployed near the seaward end of the navigation channel (CM2). RDI supplies utility software for recovering and processing data. Newer versions of the software allow Windows®-based use of the software. However, the original DOS software supplied with the moored instrument was used for processing the recorded data. The RDI program BBSC was used to download the binary data file from the ADCP's memory and store it on the computer in binary form. An RDI program called BBLIST was used to convert the binary data into ASCII files. Three data-quality parameters were recorded by the current meter: correlation magnitude, percentage of good pings, and backscatter intensity. Correlation magnitude is a measure of the pulse-to-pulse correlation in a ping for each depth cell. Percentage of good pings is a data qualifier representing the percentage of pings having good data based on the signal-to-noise threshold. Backscatter intensity is a measure of the strength of the acoustic signal that is returned to the current meter in each depth cell. A low value can indicate an electronic failure or depth cells at the furthest ranges that are too far away from the instrument. At the approximately 35-ft deployment depth, all depth cells were well within range. However,

the recorded backscatter intensity plays an important role in determining where the sea surface is. The acoustic signal transmitted by the ADCP will be reflected by the surface and make it appear that the instrument is still measuring valid velocities at greater ranges than the actual depth. However, the backscatter strength from the surface is relatively strong, and indicates the range at which to terminate the velocity measurements in the data processing.

The correlation magnitudes and the percentage of good pings were reviewed for each ADCP measurement. An in-house extraction program was used to create files with only the parameters needed for further processing. These parameters are the time of the measurement, the vertical orientation and heading of the instrument, the water temperature, and the backscatter intensity. The current-meter orientation and heading, at this stage in the processing, are data-quality indicators. If the current meter is tilted more than 20 deg from the vertical, it will not operate correctly. The orientation and heading can also show if the mooring was snagged by an anchor or trawl, and, if it was, when it happened.

Using an in-house analysis program, the inflection point in the backscatter intensity within the depth range of 29 to 45 ft was located in each ADCP vertical profile. The depth was calculated for the depth cell that was one cell above the one in which the inflection occurred, and new files were produced that kept all the depth cells up to one cell less than the inflection cell. The calculated depth was plotted and compared to the time series record of the water-level recorder attached to the mooring. An in-house program used these files of processed vertical current profiles to calculate vertical vector averages of the current from the first cell, at a depth of approximately 3 ft above the sea floor, to the last cell in the processed profile. These vector averages were stored in an ASCII file and plotted in time series plots.

The first step in processing the current transect survey data was to compare the survey field notes with the ASCII files of GPS navigation data recorded for each transect. There were two objectives in the process. The first was to verify that the field notes matched the file numbers to the correct survey transect lines. The times and locations in the GPS navigation files provided this information. The second objective was to determine the exact time when each survey line was acquired and started by the survey vessel, and when the line was complete. By matching these

times to the times of the measurements recorded in the ADCP data files, data not along the transect line were eliminated from further processing.

The Windows®-based software package supplied by RDI used to acquire the current transect data (WinRiver) was used for the next step in processing the transect data. WinRiver converted the binary data recorded by the ADCP to ASCII output files. Two data-quality indicators are given in these files. They are percentage of good pings and backscatter intensity. These two parameters were reviewed for data quality. Correlation magnitudes are not shown in these files, as they are for the moored current meter, because unacceptable correlation magnitudes during the survey would have been shown on the transect survey output computer display, and the survey would have been stopped until the problem was corrected. In addition to the current speeds and directions in the depth cells, the WinRiver ASCII output files also contain the times of measurements, total depths, latitudes and longitudes at the locations of the measurements (from the GPS), and the total volume transport across the transect line from the current. From these files, an in-house program created files that contained the times, latitudes and longitudes, and depths for the measurements, and the current speeds and directions in the cells down to a level equal to 94 percent of the total depth. In the final 6 percent of the depth, acoustic side-lobe interference adversely affects the measurements. Using these files, an in-house program calculated the vector current average over the water column from the first depth cell, at a depth of approximately 3 ft below the surface, to the last depth cell in the processed profile. These vector averages were stored in ASCII files and plotted in time series plots.

### **Data Return and Assessment of Data Quality**

NOAA tide data were available from the station in Boston's inner harbor for the deployment period, except from 22 January to 4 February 2005. There is no information on the NOAA Web site that explains why the data are missing for this period. However, the NOAA gage measures the distance to the sea surface inside a stilling well with an acoustic sensor positioned above the sea surface, and it may be affected by ice in the stilling well. Based on information supplied by the owner of the survey vessel (the *Sakonnet*) about conditions during this period, there is a good chance that the data loss was due to ice. At all other times during the field deployment period, NOAA has verified their data as being good.

Unlike the NOAA gage, the ERDC gages measure the water pressure above the gages without a stilling well. The effect of ice on these measurements is difficult to determine, especially without specific knowledge of the ice conditions right at the sensors. However, there are no obvious differences in the data from these gages during times when it was known that there was no ice, and during times when there may have been ice present. All indications are that at three of the gage locations, 100 percent good-data were obtained for the entire deployment period. As already noted, the fourth gage (TG2), on the current-meter mooring near the seaward end of the navigation channel, recorded water level during the entire deployment period, but the data are good only about 60 percent of the time.

As discussed earlier, the moored current meter near the entrance to the inner harbor recorded no data. For the other moored current meter (CM2), all data-quality indicators showed that it acquired 100 percent good-data for the entire deployment period and that the current meter was not disturbed at any time.

During the first transect current survey, the data quality indicators show that all the data are good. However, the wind and rough sea state on 11 November 2004 were such that the transect lines had to be confined to the western extent of the navigation channel between Spectacle and Castle Islands (lines T3, T4, and T5 in Figure 12). A failure of the shipboard generator during this survey ended the survey after 9.5 hr, instead of the planned 12 hr.

During the second transect current survey in February, the eastern extent of the navigation channel was surveyed out to a line from Deer Island to Long Island (line T1 in Figure 12). The data-quality indicators for the second survey show that on two of the lines surveyed, all the recorded data are good. As a result of the slower sound speed in the colder winter waters, the ADCP was unable to measure currents at all depths on the deepest transect line (i.e., T1 between Deer Island and Long Island). Failure to record data began at a depth of about 60 ft, and in the deepest places along this line, there are no data for the near-bottom portion of the water column. During this survey, the survey vessel had to return to the dock during daylight to avoid ice present in the harbor. As a result, the survey lasted 7.5 hr instead of the planned 12 hr.

There are verified NOAA wind data for all of the deployment period, with 3.9 percent observations labeled invalid. The longest period of invalid data is 11 hr, and the second longest is 5 hr.

The extent of the good-data coverage is shown in Figure 13. In reference to the original SOW, water elevation data were obtained for 3 months at four sites, instead of the 1 to 2 months of data at two sites, as originally proposed. Moored current data were obtained at one site for 3 months, instead of the 1 to 2 months at one site that was in the original SOW. Two transect current surveys were performed, as proposed. Wind data were obtained for nearly the entire deployment period, as proposed.

## Analysis

The NOAA anemometer at Logan Airport is placed at an obstruction-free location near the center of the runway area. The sensor is 20 ft above the ground. The wind speeds and directions from the measurements at this location during the deployment period, with the gaps for invalid data filled by linear interpolations, were sorted into 30-degree direction categories. The directions are the directions the wind is blowing from in degrees true north. The speeds in each direction category were sorted into 5-ft/sec speed categories. Table 3 shows the percentage of the total number of observations in each category. There were two major storms during the 10 November 2004 to 8 February 2005 deployment period. One occurred on 27 December 2004, when a maximum wind speed of 47 ft/sec from 50 deg was measured at Logan Airport. The other one, on 23 January 2005, had a maximum wind speed and direction at Logan Airport of 57 ft/sec from 60 deg. The wind speed during the January storm is the maximum value observed during the deployment period. Table 3 is a statistical summary of the wind observations from Logan Airport; it shows that the strongest winds were from 345 to 15 deg and 45 to 75 deg. A majority of the winds were from the northwest quadrant, and almost half (47.71 percent) were 10 to 20 ft/sec. Overall, the statistics show a sustained period of strong winds, with two major storms.

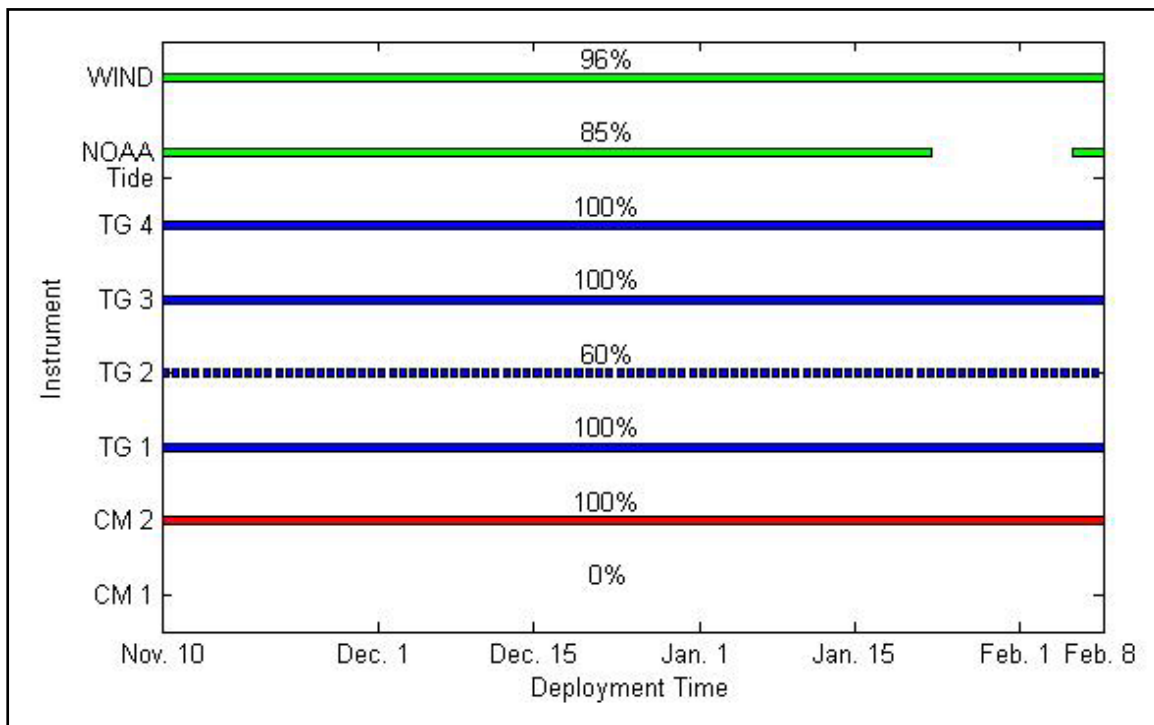


Figure 13. Summary of data return for deployment period. TG's are water-level recorders and CM's are moored current meters (see Figure 2 for instrument locations).

Table 3. Summary of wind observations made at Logan Airport during the deployment period (10 November 2004 – 8 February 2005).

		Wind Direction (deg T)												Total %
		345-015	015-045	045-075	075-105	105-135	135-165	165-195	195-225	225-255	255-285	285-315	315-345	
Wind Speed (ft/sec)	0-5	0.46	0.27	0.27	0.23	0.32	0.69	0.41	0.32	0.18	0.14	0.18	0.27	3.75
	5-10	2.61	0.96	0.46	0.91	1.37	1.37	1.01	1.74	0.78	0.73	1.23	1.37	14.53
	10-15	3.98	1.01	0.37	0.96	0.91	1.23	2.51	1.69	1.65	2.61	3.56	5.16	25.64
	15-20	3.02	1.65	0.27	0.46	0.69	0.59	0.55	2.24	2.33	3.24	3.06	3.98	22.07
	20-25	1.51	0.64	0.18	0.41	0.50	0.37	0.37	1.87	1.69	2.19	2.74	3.11	15.59
	25-30	1.42	0.18	0.14	1.10	0.27	0.14	0.14	1.10	0.96	1.28	1.92	1.23	9.87
	30-35	0.69	0.09	0.41	0.64	0.27	0.05	0.18	0.37	0.23	0.69	1.51	0.91	6.03
	35-40	0.09	0.00	0.09	0.05	0.05	0.00	0.09	0.18	0.00	0.32	0.18	0.00	1.05
	40-45	0.23	0.05	0.00	0.00	0.05	0.00	0.09	0.05	0.00	0.09	0.00	0.00	0.55
	45-50	0.23	0.00	0.18	0.05	0.00	0.00	0.05	0.09	0.05	0.05	0.00	0.00	0.69
	50-55	0.05	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14
	>55	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09
Total %		14.26	4.84	2.56	4.80	4.43	4.43	5.39	9.64	7.86	11.33	14.40	16.04	100.00

To evaluate the wind-driven currents generated near the seaward end of the navigation channel, the depth-averaged (east-west and north-south) components of the current velocities measured by the moored ADCP were put through a low-pass Butterworth filter with a cutoff frequency (0.7) of  $1/26 \text{ hr}^{-1}$  to remove the tidal signal. During the 23 January 2005 storm, the winds increased from above 32 ft/sec at 2354 (GMT) on 22 January, when they were blowing from 90 deg, to a maximum speed of 57 ft/sec (GMT) from 60 deg at 0554 (GMT) on 23 January. The wind direction then (later on 23 January) moved toward blowing from the north, and dropped below 32 ft/sec at 2100 (GMT) on the same day. During this time, the water-level records show the mean tide level in the harbor increased as the wind drove water into the harbor. The 26-hr (period) low-pass filter catches the contribution of the storm surge outflow from the harbor to the currents as a residual 0.56 ft/sec current toward 69 deg that enhanced the ebb currents near the end of the day on 23 January when the wind stress relaxed. The events during the 27 December 2004 storm repeated this pattern. The wind speed increased from 18.7 ft/sec to 45.6 ft/sec from 60 deg at 2254 (GMT) on 26 December, reached the maximum of 47.2 ft/sec from 50 deg on 27 December, and decreased below 18.7 ft/sec at 0554 (GMT) on 28 December. The filtered residual current showed a 0.54 ft/sec current toward 70 deg that enhanced the ebb currents near the end of the day on 27 December.

Other than during these two storms, the maximum current speeds after filtering were all less than 0.36 ft/sec, and there are nine periods in the record where the residual current speeds were greater than 0.30 ft/sec. During these periods, there is no obvious consistent pattern to their occurrence and wind speed and directions. Since there is very little freshwater input into Boston Harbor, density-driven currents are not likely to be contributing to the residual currents after filtering. Two other possible contributors are tide-induced residual currents and wind-driven currents.

To see if some statistical relationship between the winds and the currents might exist, power spectral estimates of the filtered velocity components were made using an in-house MATLAB program. The program uses a Fast Fourier Transform (FFT), with trend removal and a Blackman-Harris window. The resulting spectra are shown in Figure 14. The east-west filtered current components have a peak at a period of 3.489 days. The hourly wind speed and direction data from Logan Airport were broken into

their east-west and north-south components and power spectra were made. The resulting spectra are shown in Figure 15. The east-west components of the wind also have a peak at a period of 3.489 days. The north-south components of the wind have a smaller peak at 3.012 days. Cross spectra between the wind components and the current components were made and correlations between the current and wind components were performed. It was found that at a period of 3.012 days, the correlation coefficient between the north-south component of the wind and the north-south component of the current was 0.92. However, there is insignificant energy in the current band centered on that period. At a period of 3.489 ft/sec, the correlation between the north-south component of the wind and the east-west component of the current is only 0.65. At that period, the correlation between the east-west component of the wind and the east-west component of the current is 0.93. These results indicate that east-west wind-driven currents from east-west winds are likely contributing to the residual currents after filtering. The tide-induced residual current is expected to persist throughout the record, and its strength at the CM2 location can be estimated by taking the mean of the filtered record. The tide-induced residual current was calculated to be 0.07 ft/sec toward 19 deg.

Two of the correlation analyses in the SOW were specifically designed to evaluate the importance of the residual tidal currents in the harbor. The analyses are the correlations between the mooring and transect current data, and the correlations between the current and water-level data. These analyses were to utilize current data from the mooring near the entrance to the inner harbor (CM1) where wind-driven currents were expected to be very small in comparison to the tide-induced residual currents. The analyses were not performed because there were no data from this mooring. According to Signell and Butman (1992)<sup>1</sup> the tide-induced residual circulation inside the harbor near the navigation channel has maximum speeds of about 0.33 ft/sec. In the vicinity of CM2, Signell and Butman reported tidal-induced residuals of 0.11 to 0.19 ft/sec toward 90 deg. Considering that their observations are only somewhere in the vicinity of CM2 (the paper does not give exact locations), the comparison of the analysis of the CM2 observations and their observations is reasonably good.

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<sup>1</sup> Signell, R. P., and B. Butman. 1992. Modeling tidal exchange and dispersion in Boston Harbor. *Journal of Geophysical Research* 97:15,592-16,606.

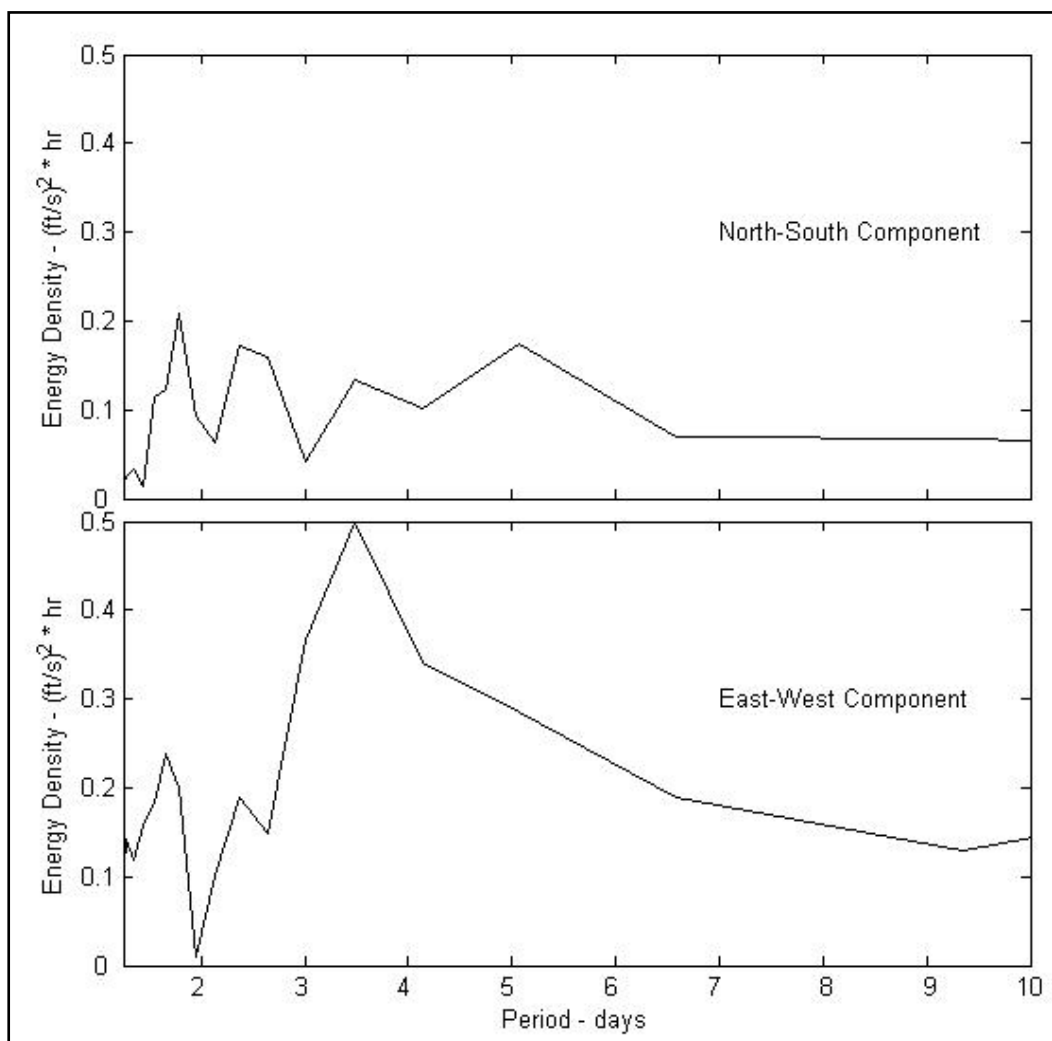


Figure 14. Power spectra of low-pass filtered (26-hr cutoff) current components of currents measured by ADCP mooring located near seaward end of navigation channel.

During the first transect current survey on 11 November 2004, the filtered residual currents at CM2 were about 0.2 ft/sec toward the west. Transects were surveyed at different times, when the survey vessel could get to them, so measurements were made at various stages in the tidal cycle. During that day, the maximum-measured tidal currents along the transects were 1.82 ft/sec along T3, 0.9 ft/sec along T4, and 1.37 ft/sec along T5 (all at ebb tide), therefore the filtered residual was 11 to 22 percent of the maximum-measured ebb speeds in November. The maximum-measured flood speeds on 11 November were 1.42 ft/sec along T3, 0.86 ft/sec along T4, and 0.77 ft/sec along T5, so the filtered residual was 14 to 26 percent of the maximum-measured flood speeds. Current meter CM2 was recovered before the second transect current survey on 8 February 2005. The maximum-measured currents at that time were 3.84 ft/sec along T1,

and 1.72 ft/sec along T3 (both at ebb). Transect T2 was not sampled at any time near peak ebb. During flood tide, the maximum-measured currents were 3.61 ft/sec along T1, 0.98 ft/sec along T2, and 1.27 ft/sec along T3. Using the same residual current speed, it was 5 to 12 percent of the measured-maximum ebb currents, and 6 to 20 percent of the measured-maximum flood currents.

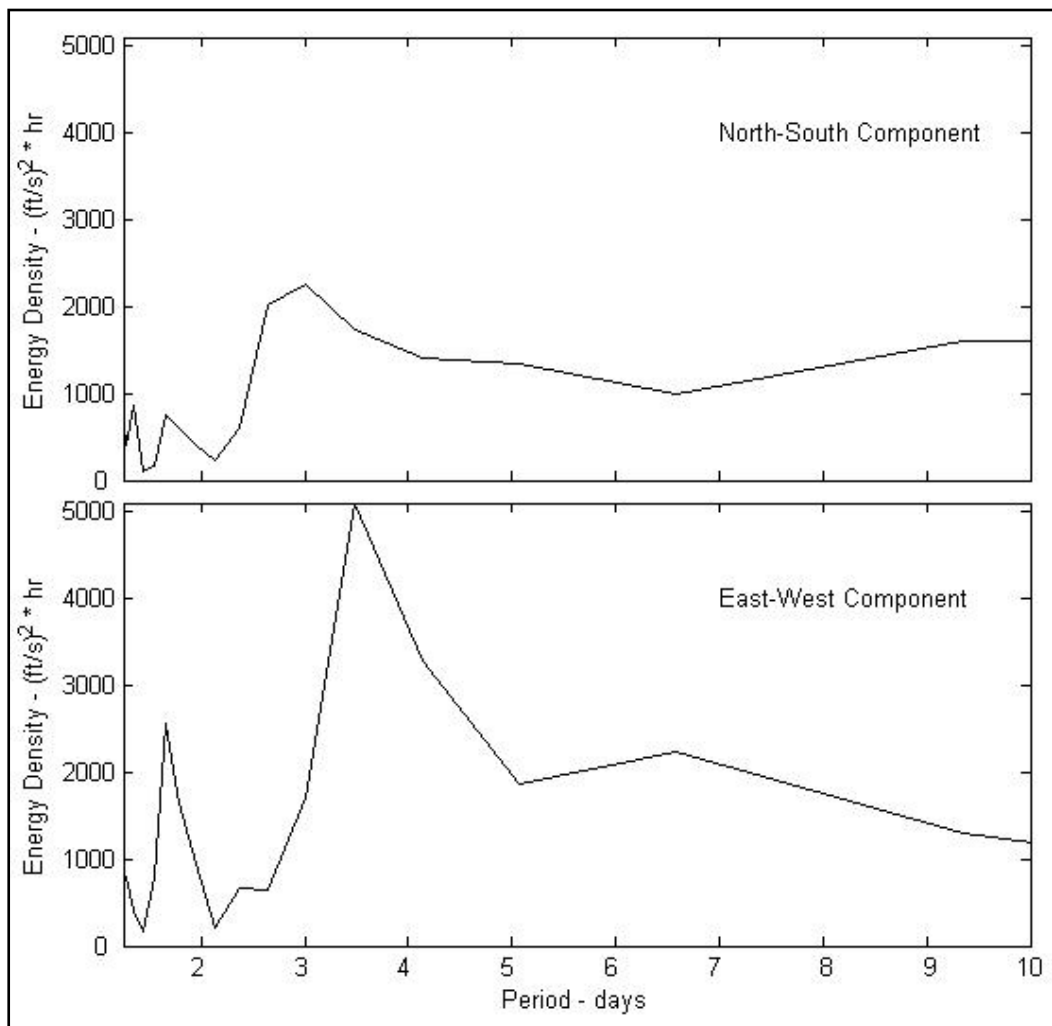


Figure 15. Power spectra of components of wind measured at Logan Airport over same period of time that currents were measured.

The maximum water-level range is defined as the largest change in elevation from high water to the low water immediately following, that was recorded at a gage location. The maximum water-level range includes wind effects, as well as the astronomical tide. Excluding TG2, which hit full scale at high tide, the range was 13.9 ft at TG1, 13.5 ft at TG3, 14.1 ft at TG4, and 13.9 ft at the NOAA gage.

## Deliverables

Plots of all data in Appendices B, C, D, E, and F are in electronic form on the project DVD as “.jpeg” files. They include:

1. Water levels referenced to the record mean levels at four locations (TG1, TG 2, TG3, TG4) and tide data referenced to established mean lower low water (MLLW) at the NOAA gage in the inner harbor (Appendix B).
2. Depth-averaged current velocities from the CM2 (Appendix C).
3. Depth-averaged currents for the transect current surveys (Appendix D).
4. Horizontal cross sections of current velocities from the transect current surveys (Appendix E).
5. NOAA wind data from Logan Airport (Appendix F).

The data are on the project DVD which was sent to the New England District as ASCII text files. The folder structure of the project DVD is in Appendix G. The formats for ASCII data files are in Appendix H and are explained in “readme” files on the project DVD.

Transect current data were put in vectorized form. This makes it possible to display the current vectors in a GIS system on the transect lines along with the bathymetry and shoreline position. An ArcView project was built to make these displays. The ArcView project and the necessary files to run it are on the project DVD.

The statistical summaries and correlations are present in this report. An electronic copy of this report is on the project DVD as a “Word” document.

## 5 Summary and Conclusions

A field data collection program in Boston Harbor, MA, was conducted from 10 November 2004 to 8 February 2005. Four water-level gages and two moored current meters were deployed for this period. In addition, daylight current transect surveys were conducted on 11 November and 8 February. One of the moored current meters failed to collect data. The other recorded good quality data for the entire deployment period. The four tide gages recorded data for the entire deployment period; however, one gage recorded full scale readings around high tide, and thus, recorded accurate water levels for approximately 60 percent of the tidal cycle. The other three gages recorded 100 percent good data. NOAA tide and wind data were obtained for the study. Probably due to ice in the harbor, there are no NOAA tide gage data 15 percent of the time. There are some minor gaps in the NOAA wind data from Logan airport that total 3.9 percent of the deployment period.

Maximum-measured ebb tidal currents in the harbor were 0.9 to 3.84 ft/sec. Maximum-measured flood currents were 0.77 to 3.61 ft/sec. In general the ebb currents were stronger than the flood currents. The data at CM2 were analyzed to evaluate the importance of the wind-driven and tide-induced residual currents. The results of the analysis were that combined, these currents are small (5 to 22 percent of the ebb currents and 6 to 26 percent of the flood currents) compared to the maximum-measured tidal currents within the harbor. The tide-induced residual current at CM2 was estimated to be 0.07 ft/sec. The technical literature shows that tide-induced residual currents within the harbor, in the vicinity of the navigation channel, are stronger than they are at CM2, with speeds of about 0.33 ft/sec.

The strongest currents at CM2 resulting from the action of the wind during major storms were associated with outflow of the storm surge from within the harbor. The analyses showed that during a major storm in December 2004, the currents were 0.54 ft/sec toward 70 deg, and during one of the worst storms (in terms of wind speed) in recent history, which occurred in January, they were 0.56 ft/sec toward 69 deg (both speeds include an estimated tide-induced residual vector of 0.07 ft/sec toward 90 deg).

## Appendix A: Scope of Work (SOW)

### Field Data Collection to Validate Hydrodynamic Model Supporting Ship Simulator Studies, Boston Harbor, MA

#### Purpose

The purpose of the field data collection program is to obtain data needed to validate a hydrodynamic model of Boston Harbor and adjacent areas (Figure A1). The currents calculated by the verified model will be input to a ship simulator, which will be used to assess the design of a navigation channel improvement project for Boston. The hydrodynamic model requires simultaneous measurements of water elevations, currents, and wind speed and direction for verification of model driving forces and calculated results.

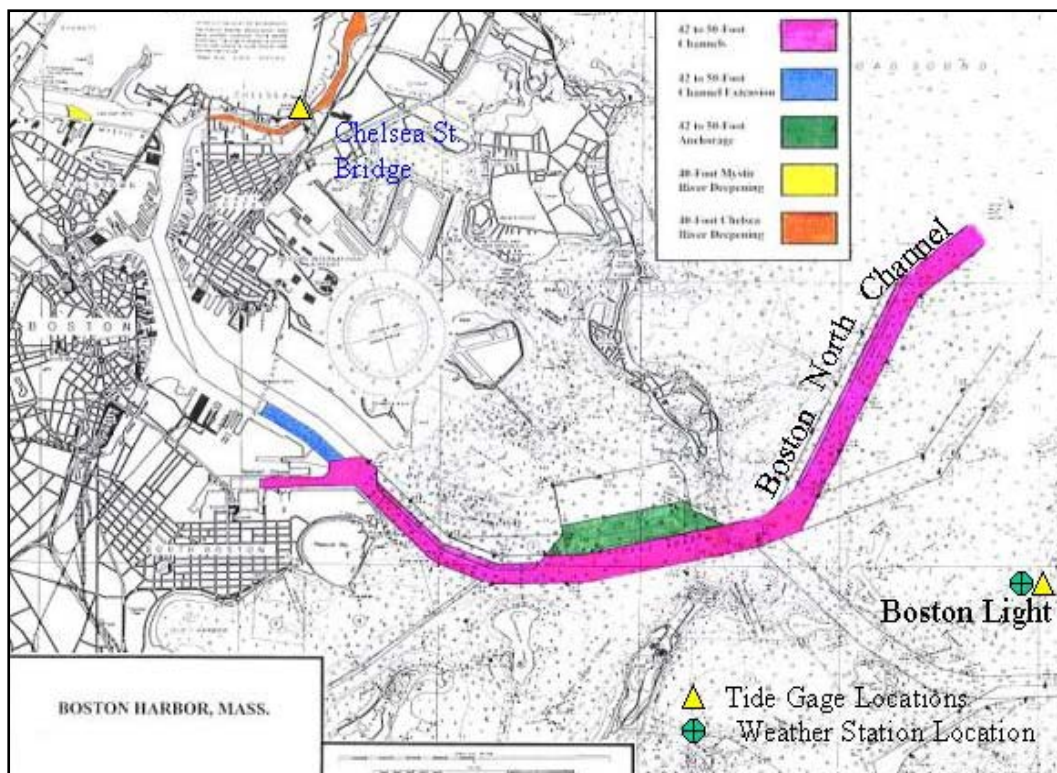


Figure A1. Boston Harbor and adjacent areas.

## Approach

Typical navigationally significant currents in Boston Harbor are primarily the result of tidal forcing. The  $M_2$  tidal component, which has a 12.42-hr period, is the most significant component. However, the currents are modulated by the  $S_2$  and  $N_2$  components, resulting in spring tidal currents that are 33 percent stronger than average currents. The spring tidal currents occur every 15 days. The wind also drives currents that can interact with, and modify the tidal-driven currents. There is relatively little freshwater input to the harbor, and resulting density-driven currents are not significant in terms of their effect on ship navigation. Water-level differences over the harbor (at any one time) are reported to be small in the absence of wind. Without wind-driven effects, water levels in the harbor are controlled by the astronomical tides, and the magnitudes and timing of their variations are nearly the same over the entire harbor. For this reason, the technical approach of the field data collection program emphasizes obtaining needed current information, and relies on minimal water-level measurements to provide elevation data.

NOAA maintains a tide measuring station in Boston's inner harbor, and has established five tidal benchmarks at various locations around the harbor. Thus the approach is to make additional tide measurements at only two locations in the harbor during the field data collection program and to use the existing NOAA tide station and benchmarks to provide the needed tidal elevation information throughout the harbor.

Current information for the ship simulator studies is needed along the navigation channel. Producing this information is the numerical model's primary role, and the focus of the field-data collection program is to obtain current data for verification of the model along the channel. The times of maximum tidal currents are predictable and can be measured by collecting data using a ship-mounted profiling current meter along transects across the navigation channel. It is proposed to do this over a tidal cycle during two separate times of spring tides. The importance of wind-driven currents is expected to be most significant in the channel in the vicinity of Boston North Channel and President Roads. Unlike tidal currents, the times and durations of strong wind-driven currents cannot be reliably predicted. Therefore, the proposed study has a current meter moored in, or very close to, Boston North Channel to collect current data every 15 min during the data collection program. The mooring will be deployed at the

beginning of the program and recovered at the end, thereby internally recording data for a 1- to 2-month period.

During this data collection program, it is proposed that wind speed and direction be collected at a site established in the harbor.

### **Data Collection Program**

The proposed field effort, as stated above, will include measuring water levels at two locations, and currents and winds, each at one location, for a 1- to 2-month period, and measuring transects of currents across the navigation channel during two spring tidal cycles. Each tidal-cycle measurement period will be approximately 13 hr long. The locations of the two proposed tide stations are Boston Light and Chelsea St. Bridge. These two locations, shown in Figure A1, have established NOAA benchmarks. Boston Light is also the location for the proposed wind-measuring station. Choosing the exact location for the Boston North Channel current meter mooring, and the locations of the tidal current transects requires further study. Time is included in the proposal to conduct the study needed for determining these locations.

### **Current Measurements**

Tidal-current transect measurements will be performed using a 1,200 or 600 kHz ADCP mounted on a boat. RDI instruments of San Diego manufacture the proposed instrument. The current meter is mounted over the side of the boat, with the acoustic transducers submerged and data are collected while the vessel is underway (Figure A2). All transect lines will be referenced to differential GPS locations through a navigation software package, HYPACK, to insure repeatability.

The ADCP transmits sound bursts into the water column, which are scattered back to the instrument by particulate matter suspended in the flowing water. The ADCP “listens” for the returning signal and assigns depths and velocity to the received signal based on techniques used in correlation sonar. The ADCP is also capable of measuring vessel velocity during collection and bottom bathymetry. Communication with the instrument for set-up, and data recording, are performed with a portable computer and manufacturer-supplied software, hardware, and communication cables.

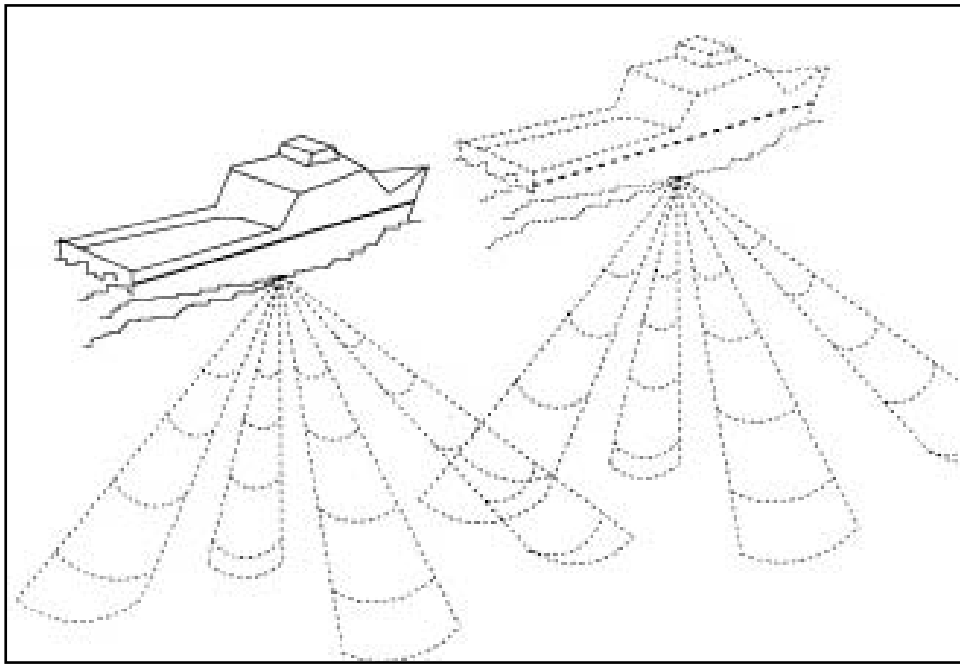


Figure A2. Typical ADCP collection operations.

Current measurements at the current-meter mooring will be made using an RDI instruments Work Horse current meter. The Work Horse is also a profiling current meter, and uses the same measurement techniques as the broadband ADCP. It will be mounted in a mooring similar to the one shown in Figure A3, and will record data internally. The mooring will be placed on the seafloor using a “slip-line,” which makes it possible to deploy it without the assistance of divers. The meter will include an acoustic release that will release a buoy in response to an acoustic signal sent through the water from the boat used for the recovery operation. During deployment the buoy is attached to the mooring, and located near the seafloor. When it is released, it floats to the surface and brings with it a line attached to the mooring. This line is used to pull the mooring to the surface, thereby making it possible to recover the mooring without divers. After recovery, internally recorded data are downloaded to a portable computer.

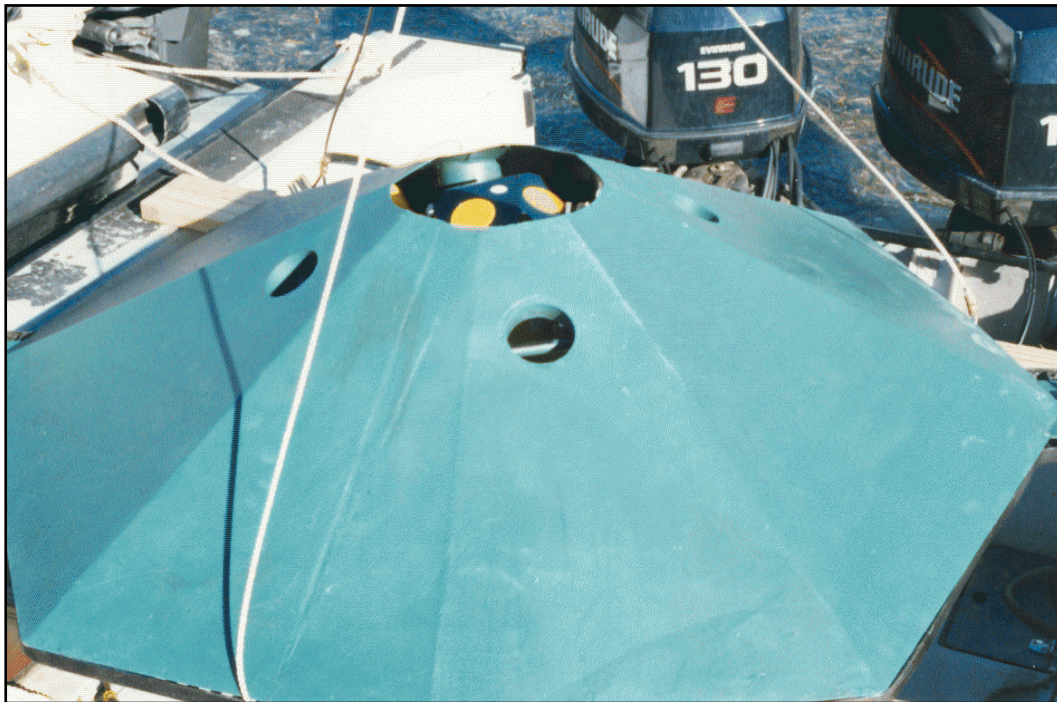


Figure A3. Current-meter mooring.

### **Water-Level Measurements**

The Coastal Leasing Microtides system is the instrument proposed for making the water-level measurements. It uses an absolute pressure gage and records data internally. The instrument is deployed below the surface, thereby reducing site security risks. The deployed position of each instrument will be surveyed to determine its location relative to the NOAA tidal benchmark at each site. A barometric pressure gage will be also deployed at each site for use in correcting water-level measurements for atmospheric pressure changes.

### **Wind Measurements**

Wind speed and direction measurements will be made at the Boston Light location using a Young Anemometer. The system uses a propeller and vane assembly to make the measurements and records data internally. It will be mounted at an open location on a 3-meter aluminum tower. The position of the tower will be surveyed using a portable GPS receiver.

### **Data Reporting**

Processing and reporting of data is focused on providing information to verify ADCIRC. This requires several steps. The first is to check the data

for quality to insure its accuracy. After the quality assurance step, data products are prepared that relate to demonstrating that certain assumptions inherent in the hydrodynamic model are valid for the study area, and that provide measures for verifying model current simulations. This requires that the processed and analyzed data be formatted to facilitate comparisons with ADCIRC output. The final step is documenting and storing the information for future reference. The proposed data products include:

- Time series of tides from measurements and interpolation at all benchmarked locations in the harbor.
- Vectorized current velocity data from the transect data entered into a GIS database.
- Time series of currents at the current-meter mooring.
- Correlations between the mooring and transect current data.
- Correlations between wind data and filtered mooring current data.
- Summary of wind statistics for the deployment period.
- Correlations between current and water-level data.

## Appendix B: Water-Level Measurement Plots

### NOAA TG Water-Level Measurement Plots

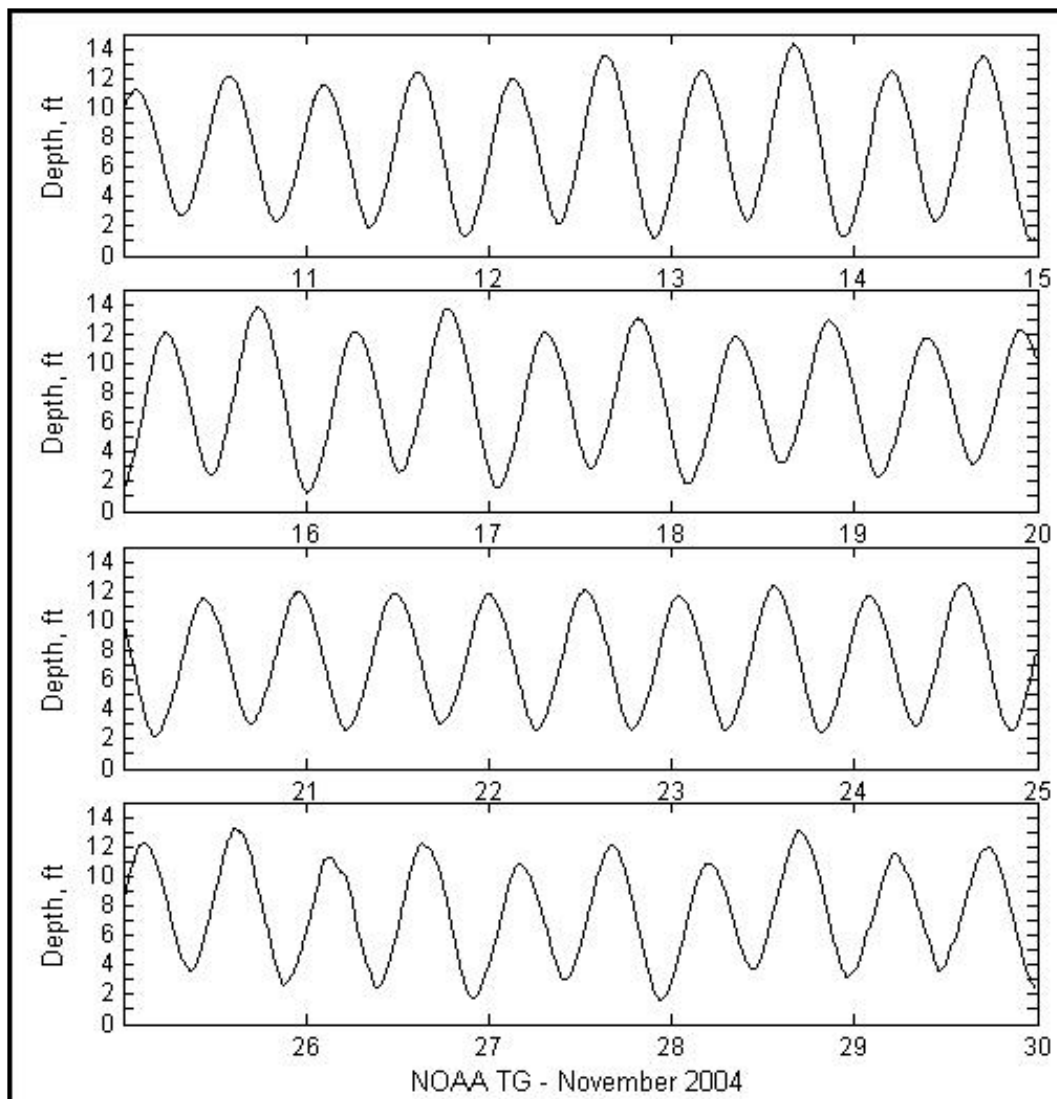


Figure B1. NOAA TG water-level measurement plot, November 2004.

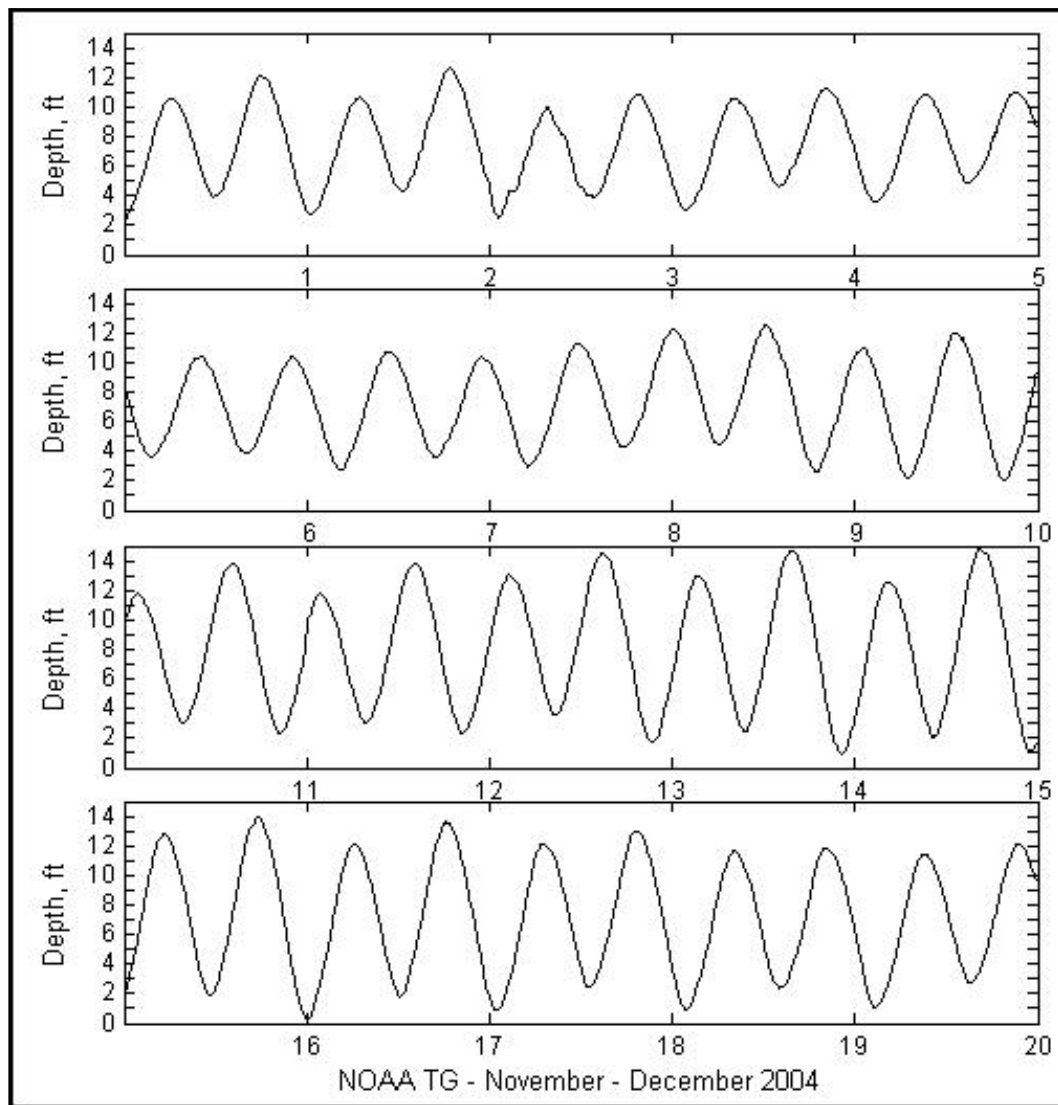


Figure B2. NOAA TG water-level measurement plot, November-December 2004.

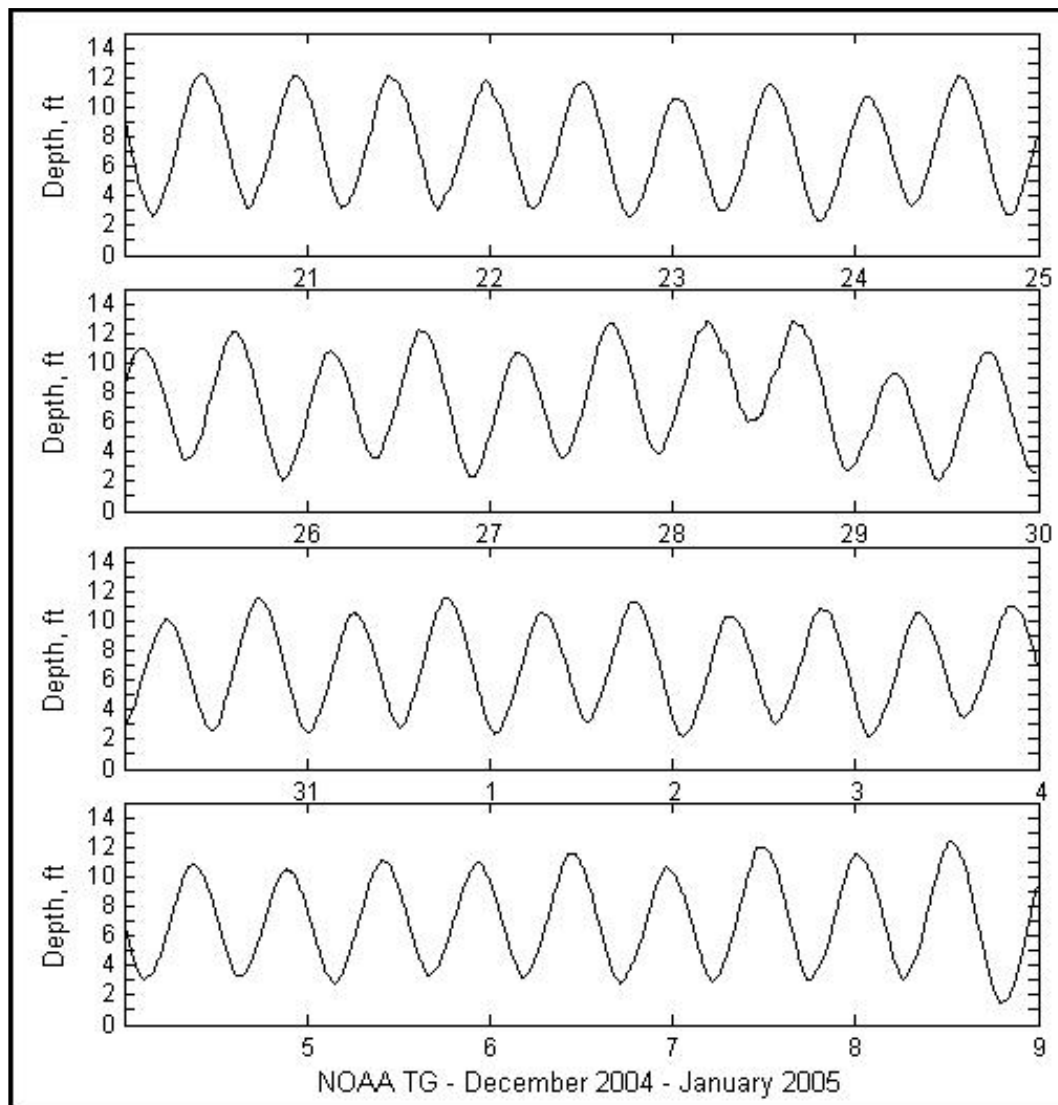


Figure B3. NOAA TG water-level measurement plot, December 2004-January 2005.

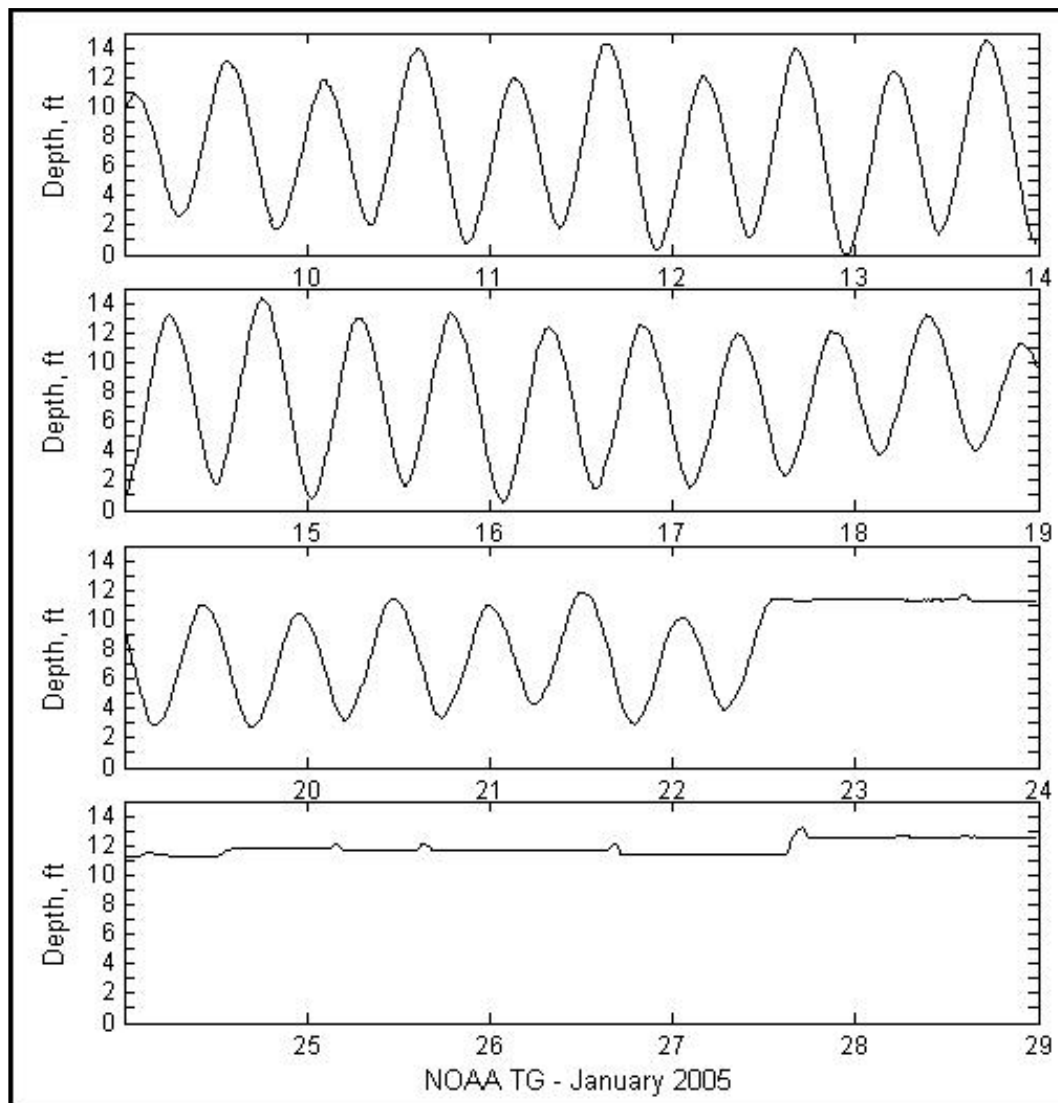


Figure B4. NOAA TG water-level measurement plot, January 2005.

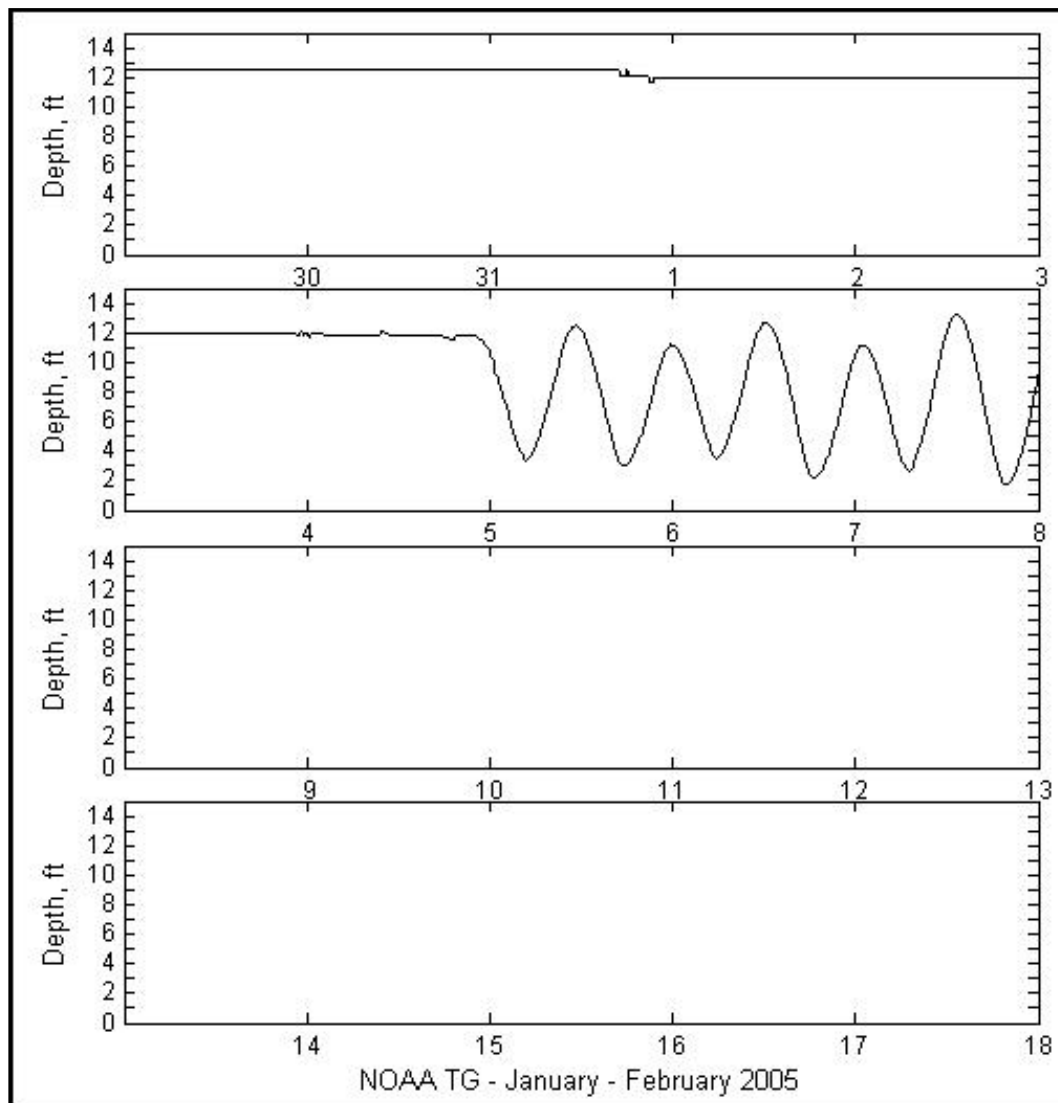


Figure B5. NOAA TG water-level measurement plot, January-February 2005.

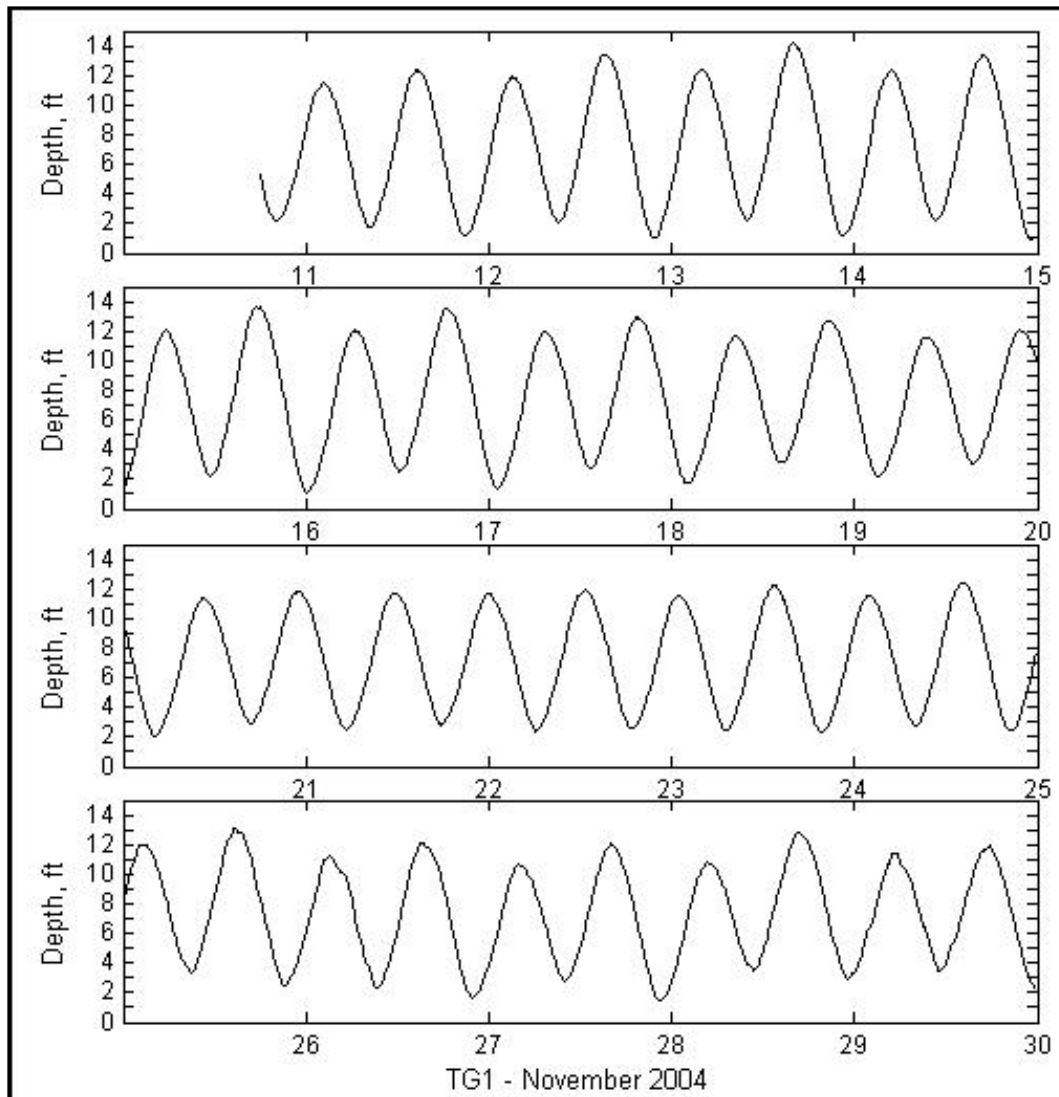
**TG1 Water-Level Measurement Plots**

Figure B6. TG1 water-level measurement plot, November 2004.

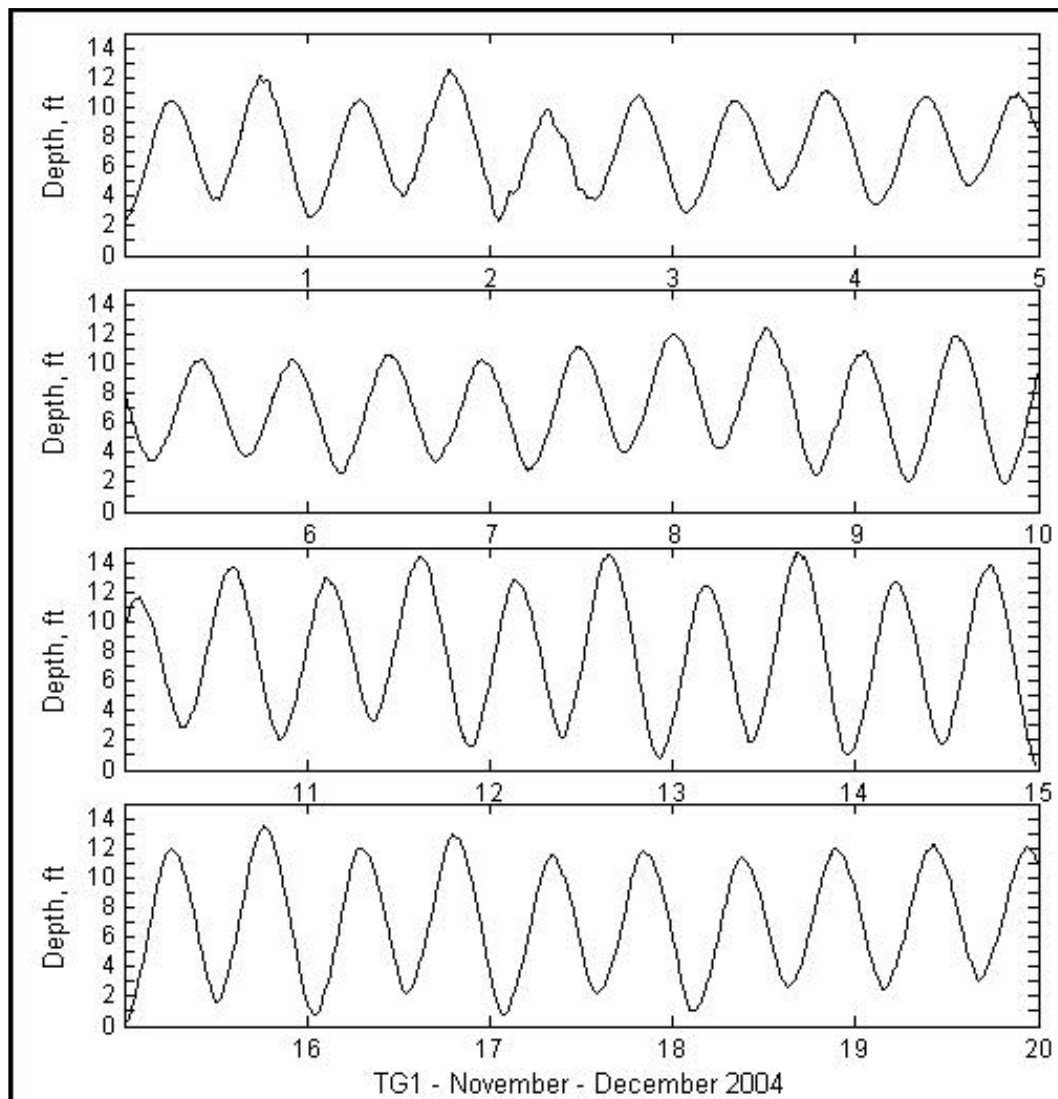


Figure B7. TG1 water-level measurement plot, November-December 2004.

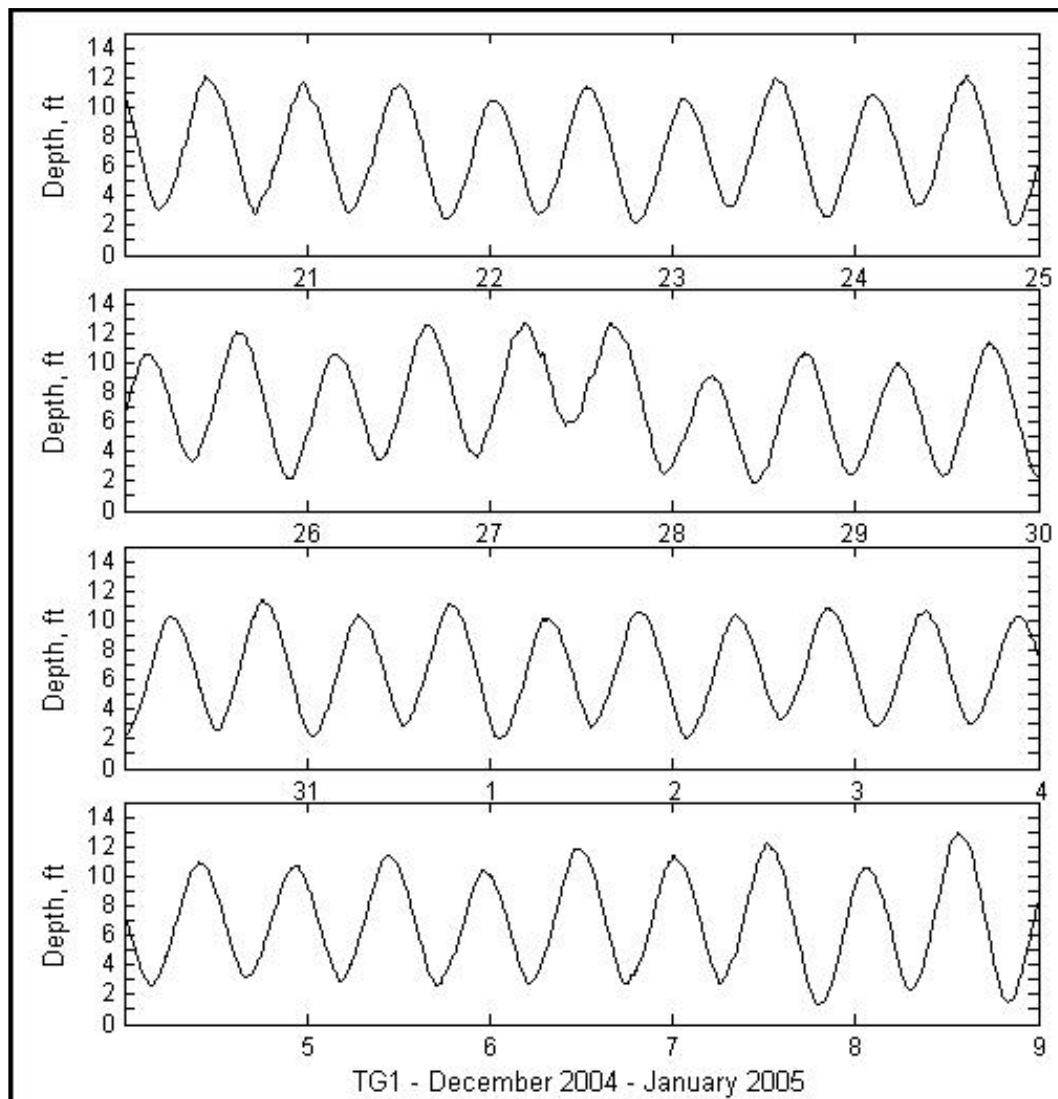


Figure B8. TG1 water-level measurement plot, December 2004-January 2005.

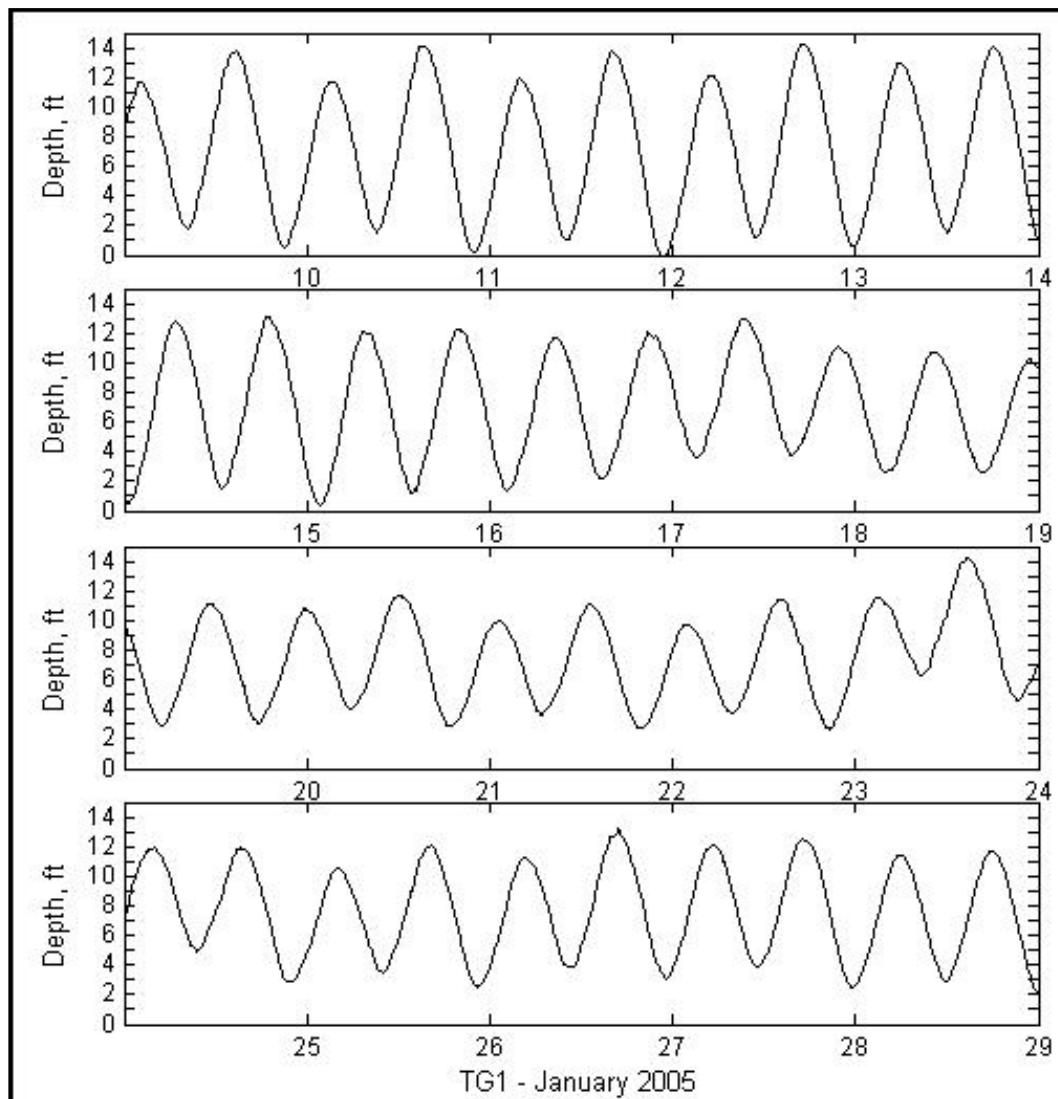


Figure B9. TG1 water-level measurement plot, January 2005.

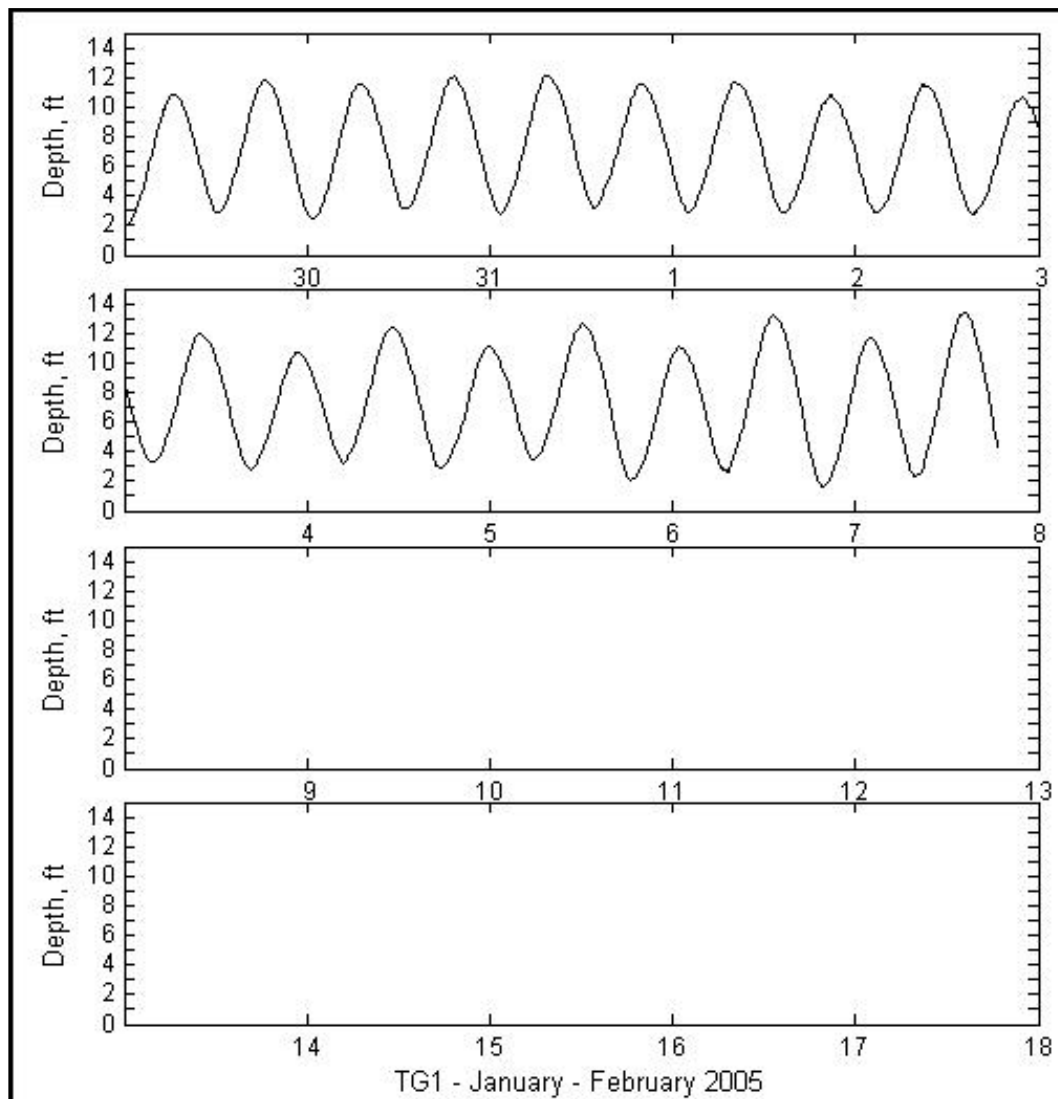


Figure B10. TG1 water-level measurement plot, January-February 2005.

## TG2 Water-Level Measurement Plots

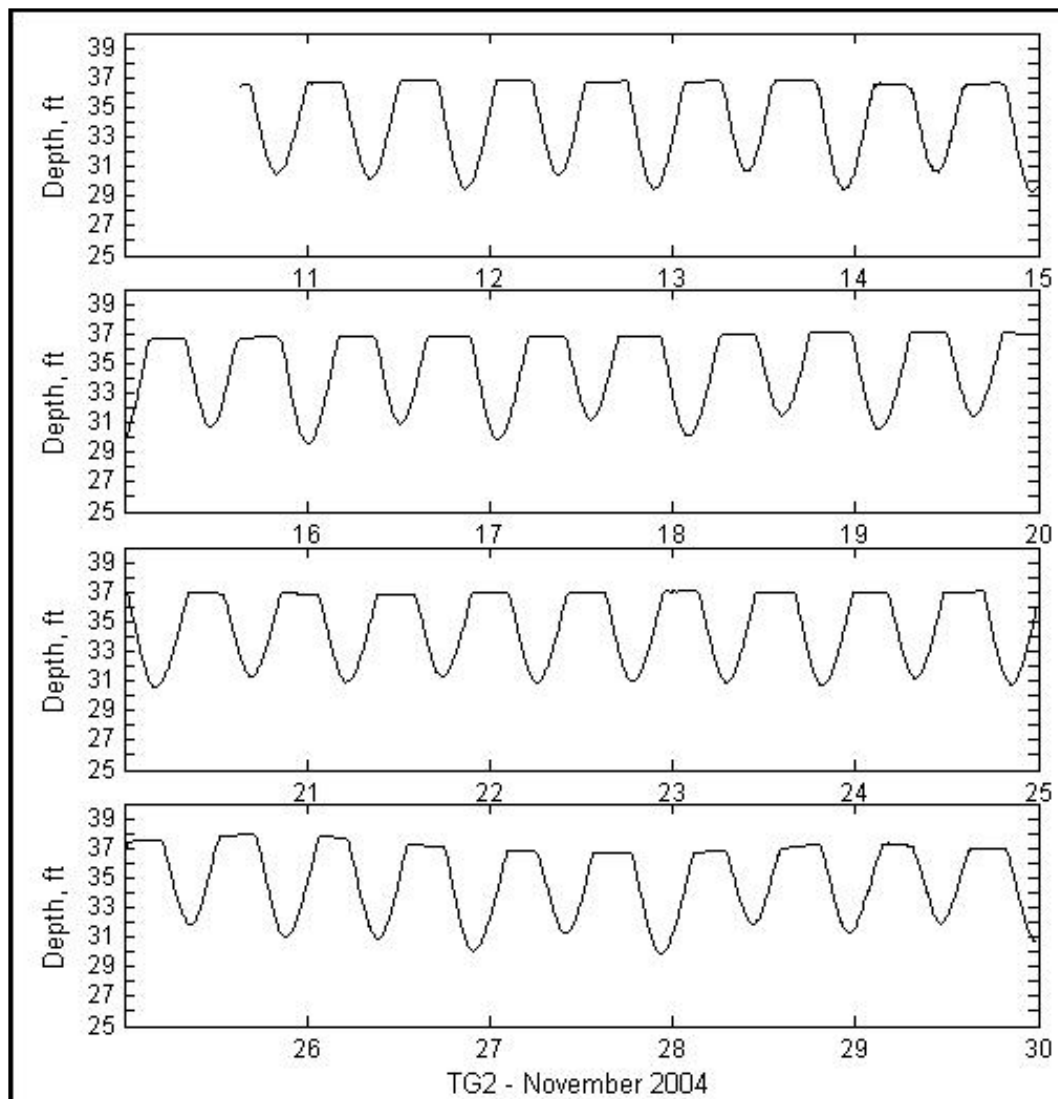


Figure B11. TG2 water-level measurement plot, November 2004.

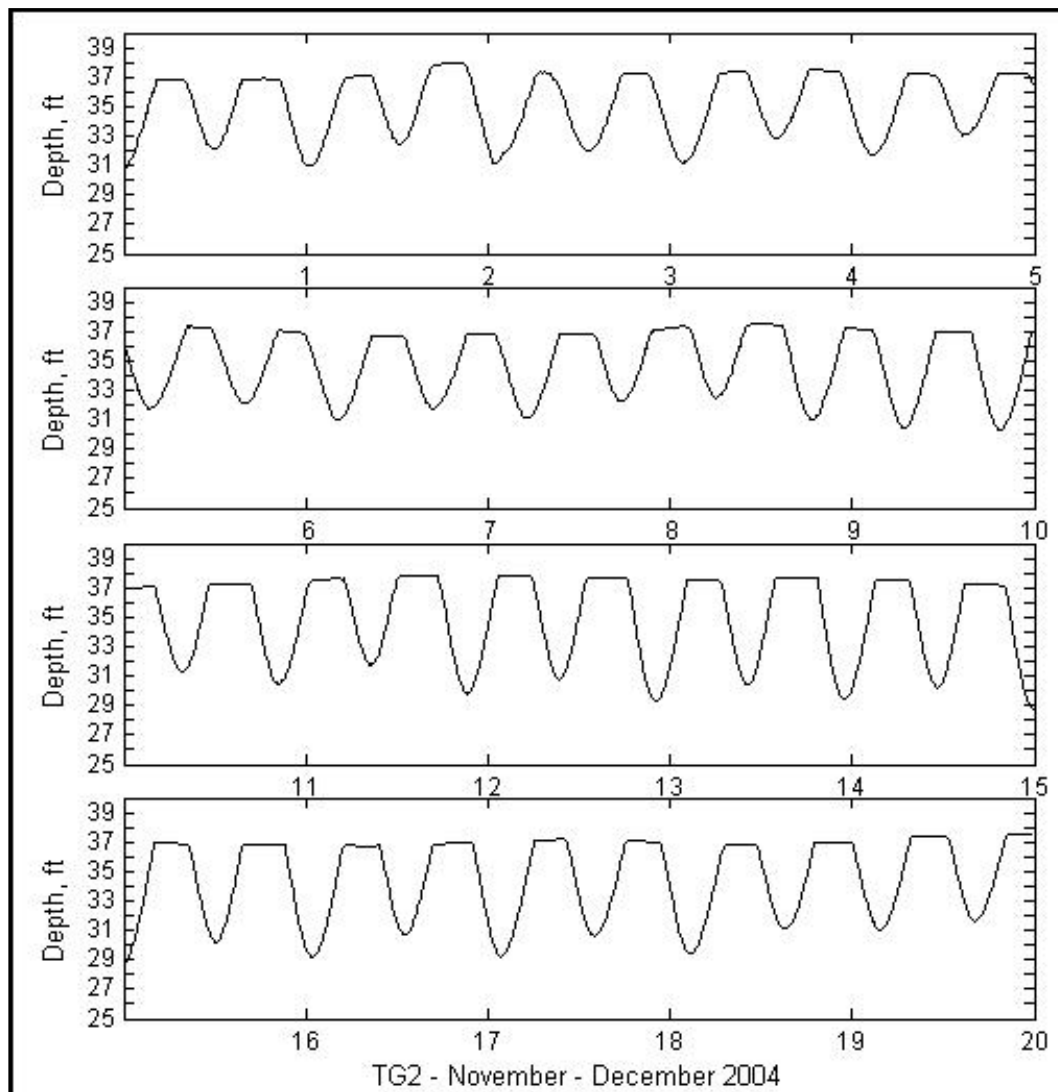


Figure B12. TG2 water-level measurement plot, November-December 2004.

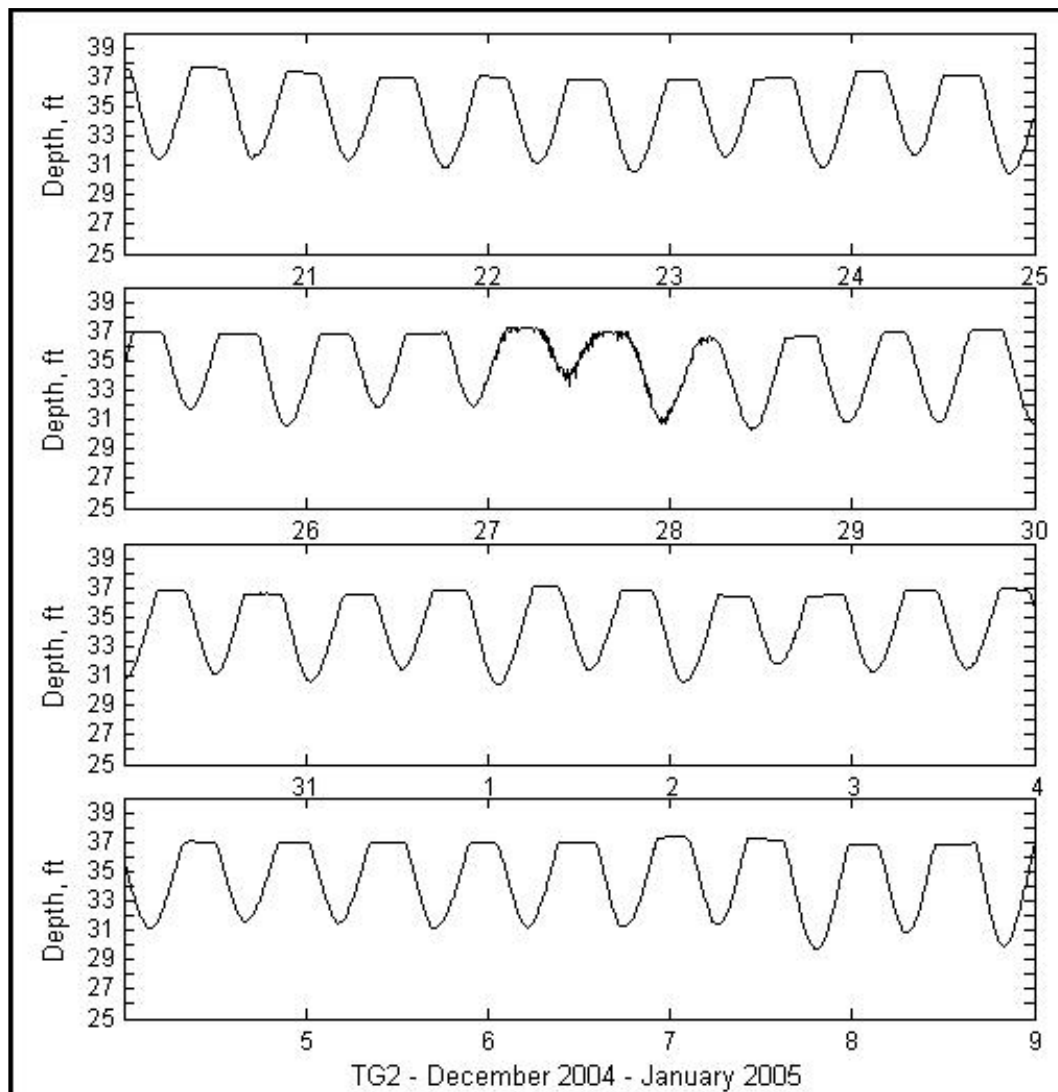
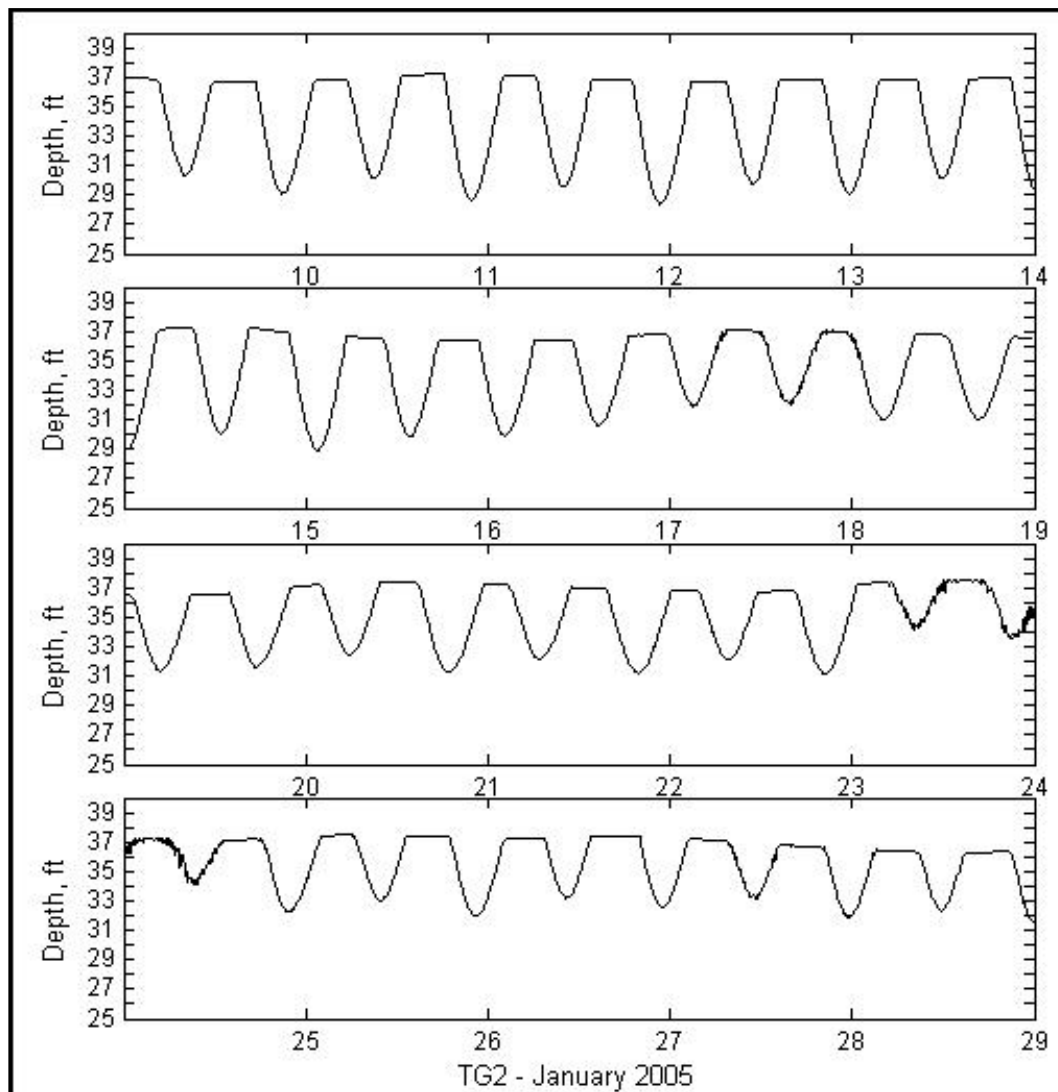


Figure B13. TG2 water-level measurement plot, November-December 2004-January 2005.



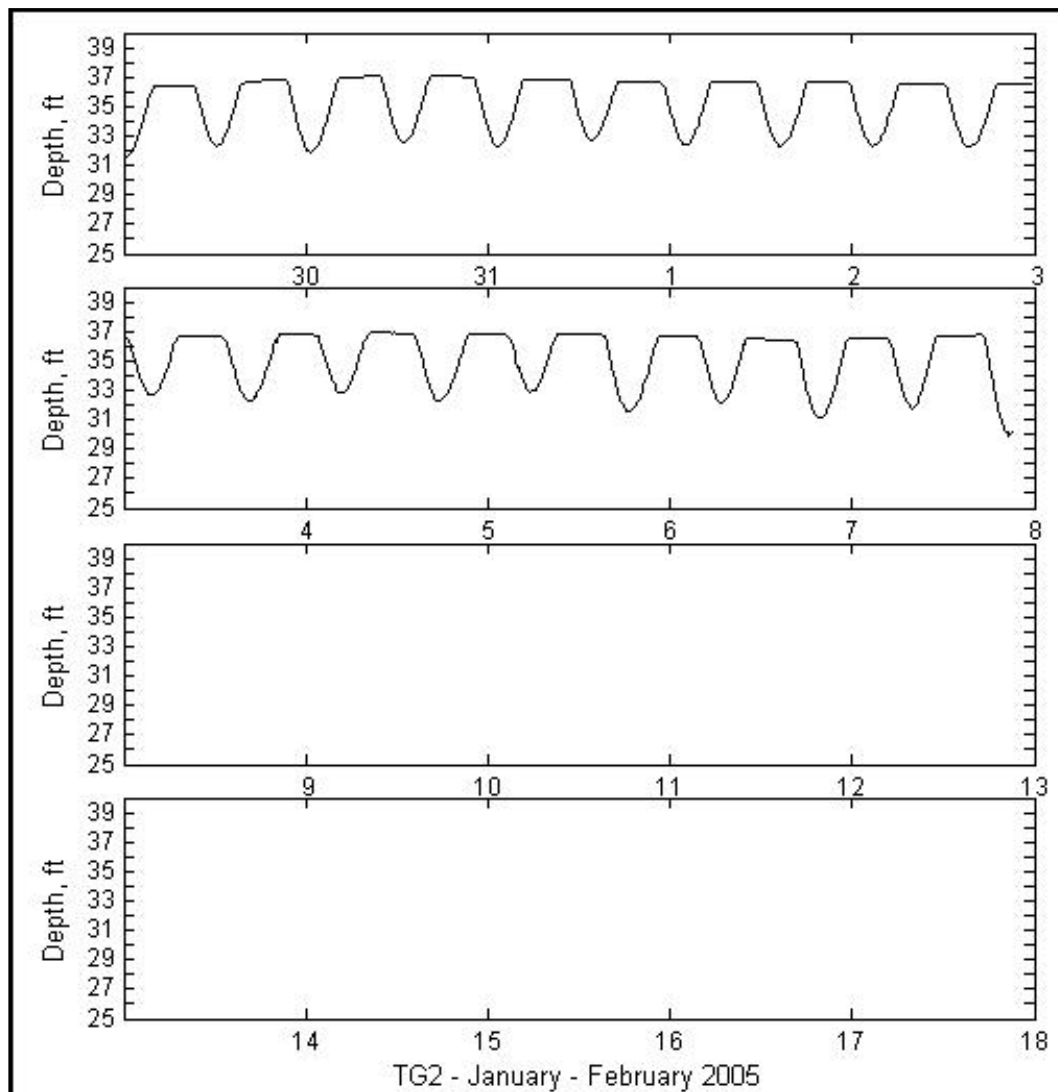


Figure B15. TG2 water-level measurement plot, January–February 2005.

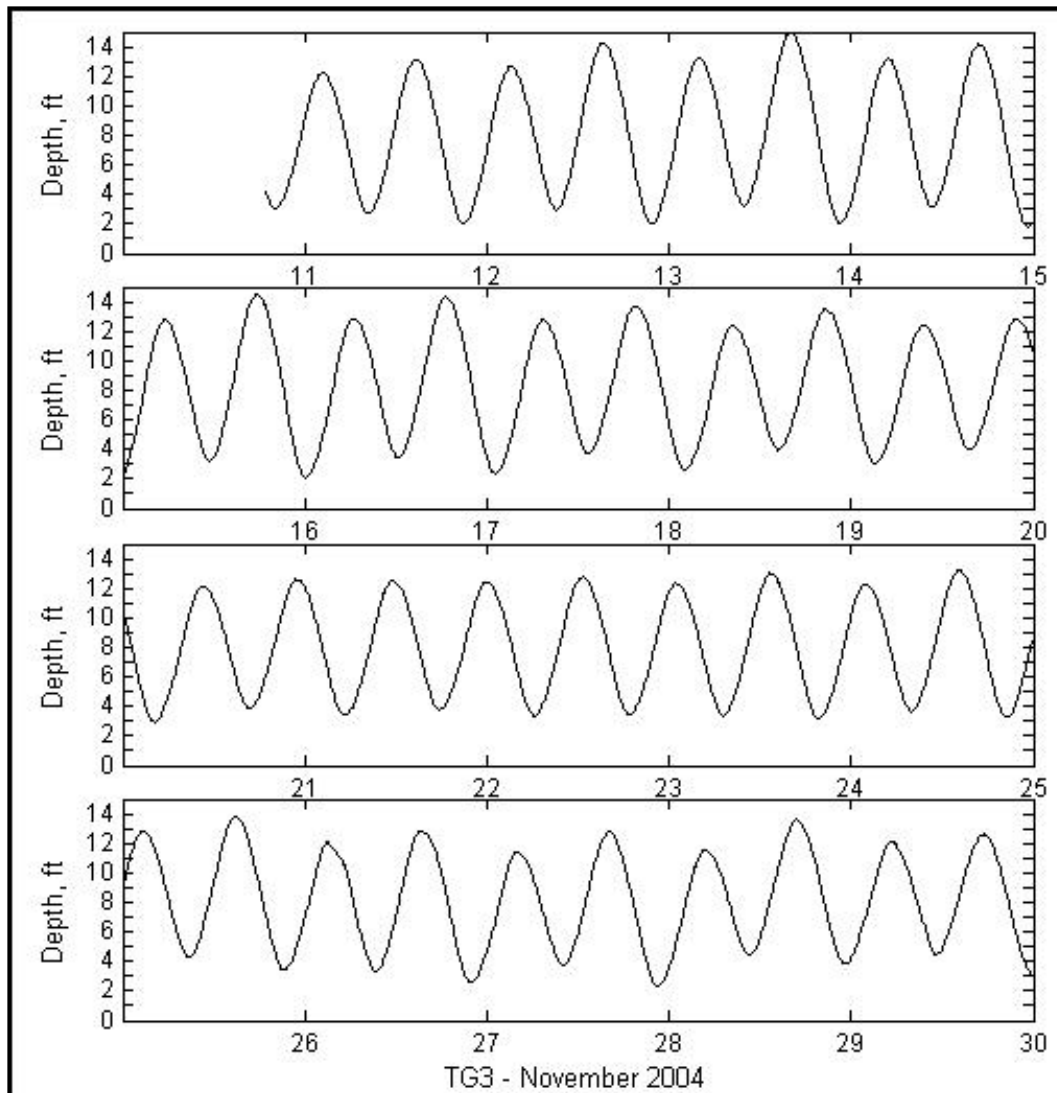
**TG3 Water-Level Measurement Plots**

Figure B16. TG3 water-level measurement plot, November 2004.

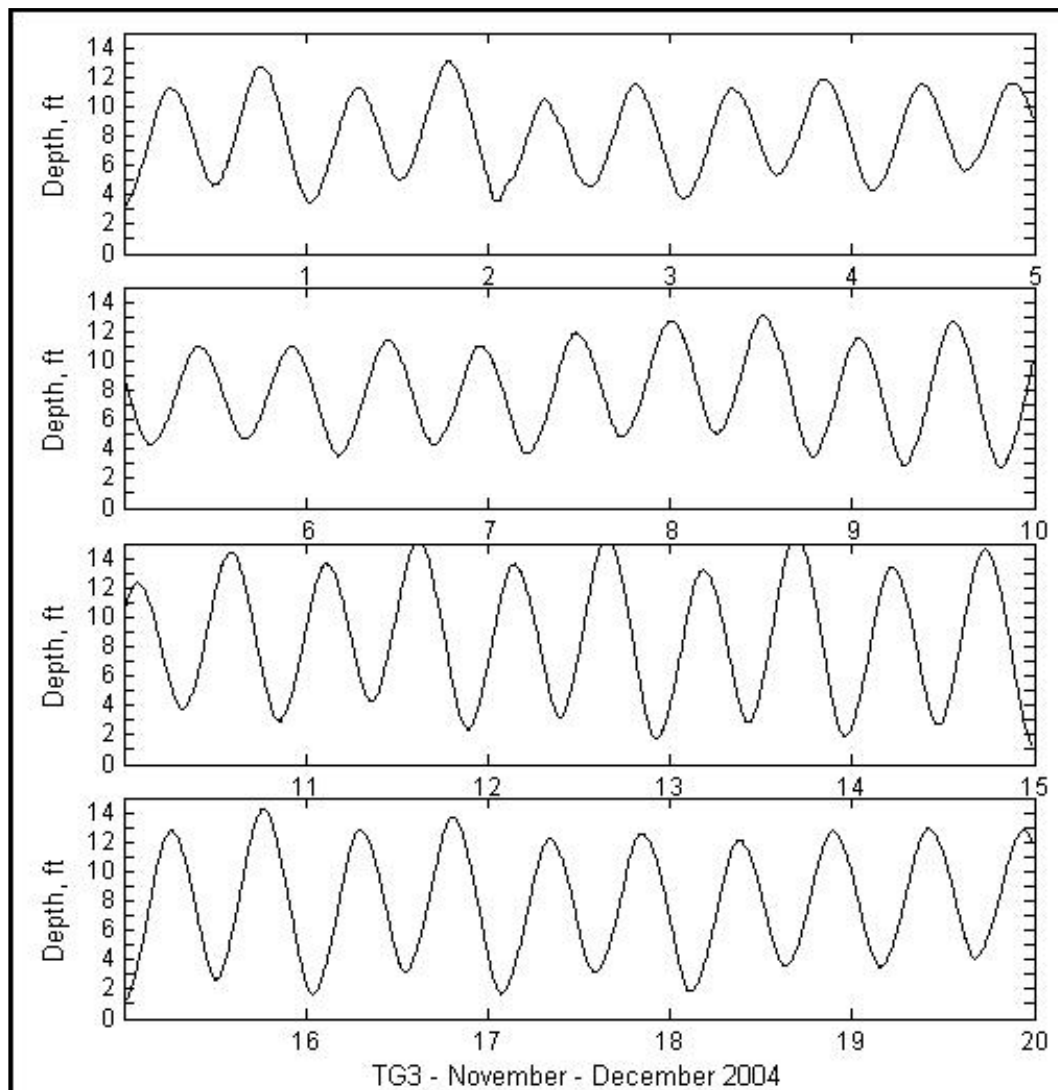


Figure B17. TG3 water-level measurement plot, November-December 2004.

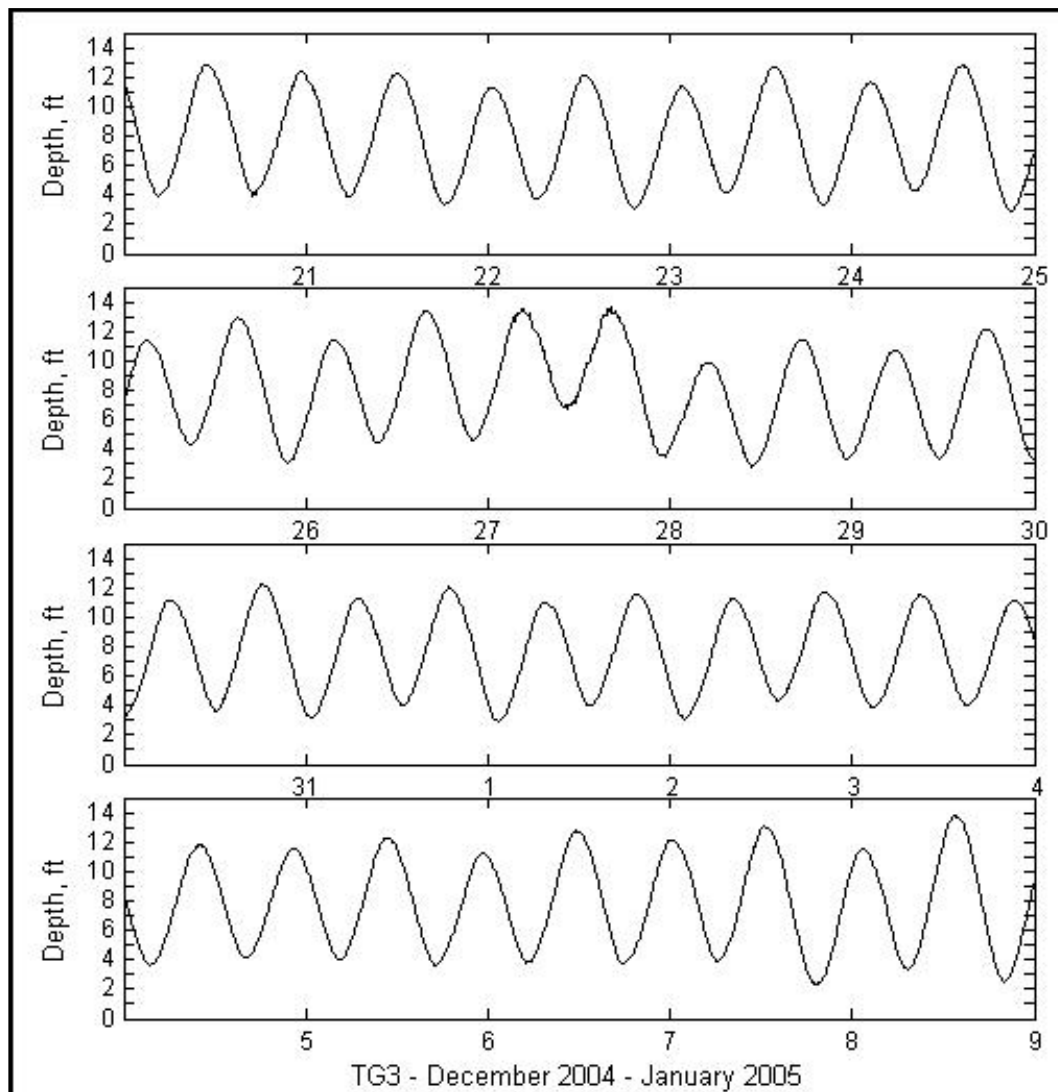


Figure B18. TG3 water-level measurement plot, December 2004–January 2005.

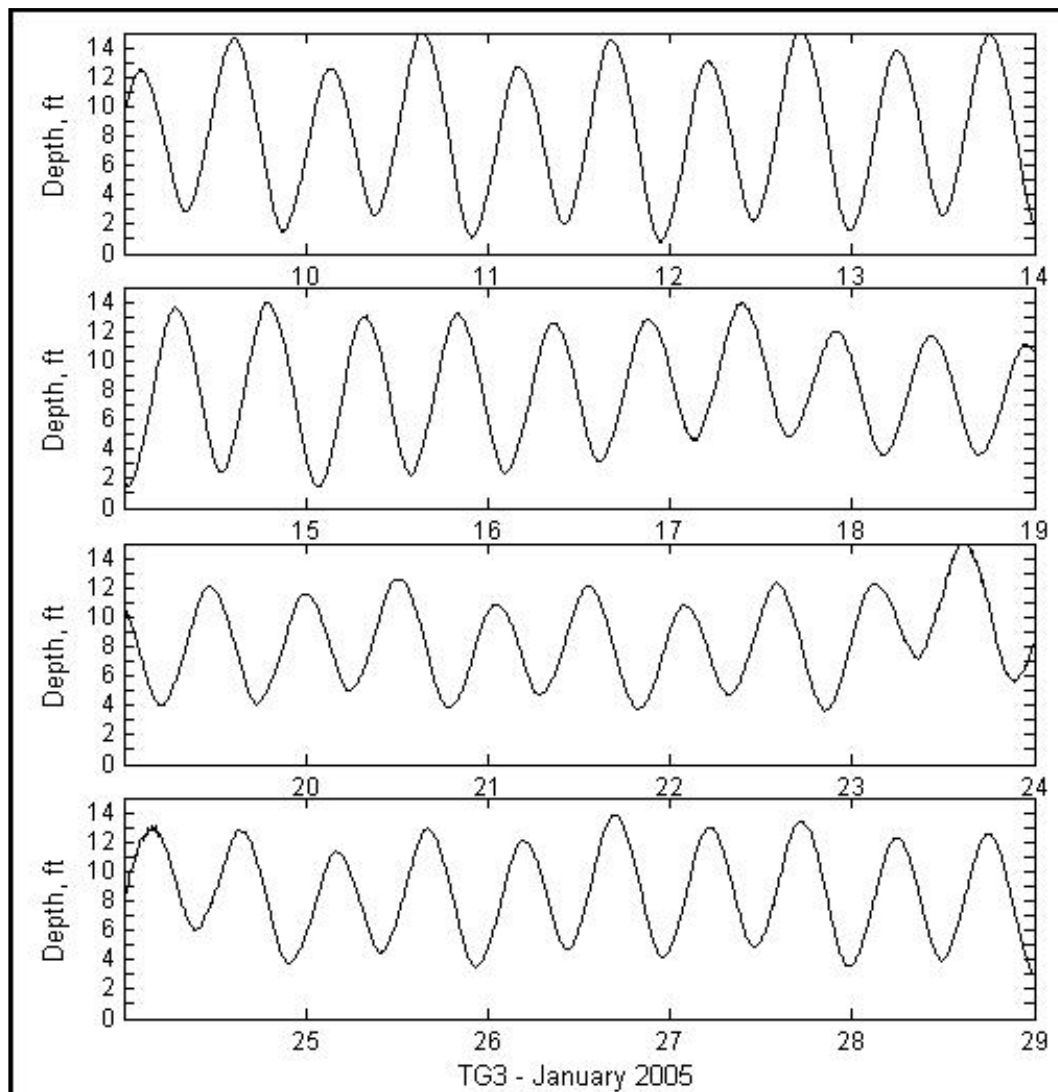


Figure B19. TG3 water-level measurement plot, January 2005.

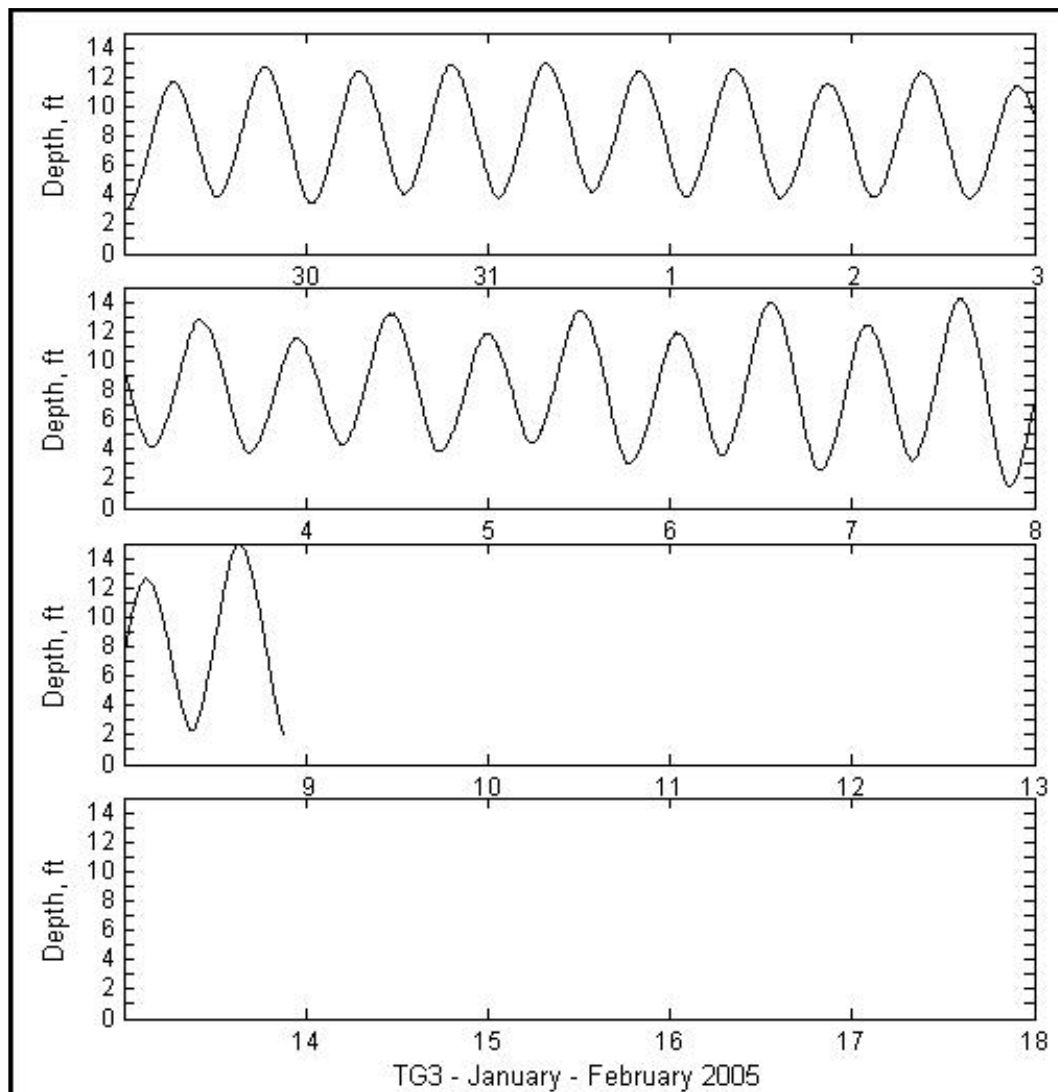


Figure B20. TG3 water-level measurement plot, January-February 2005.

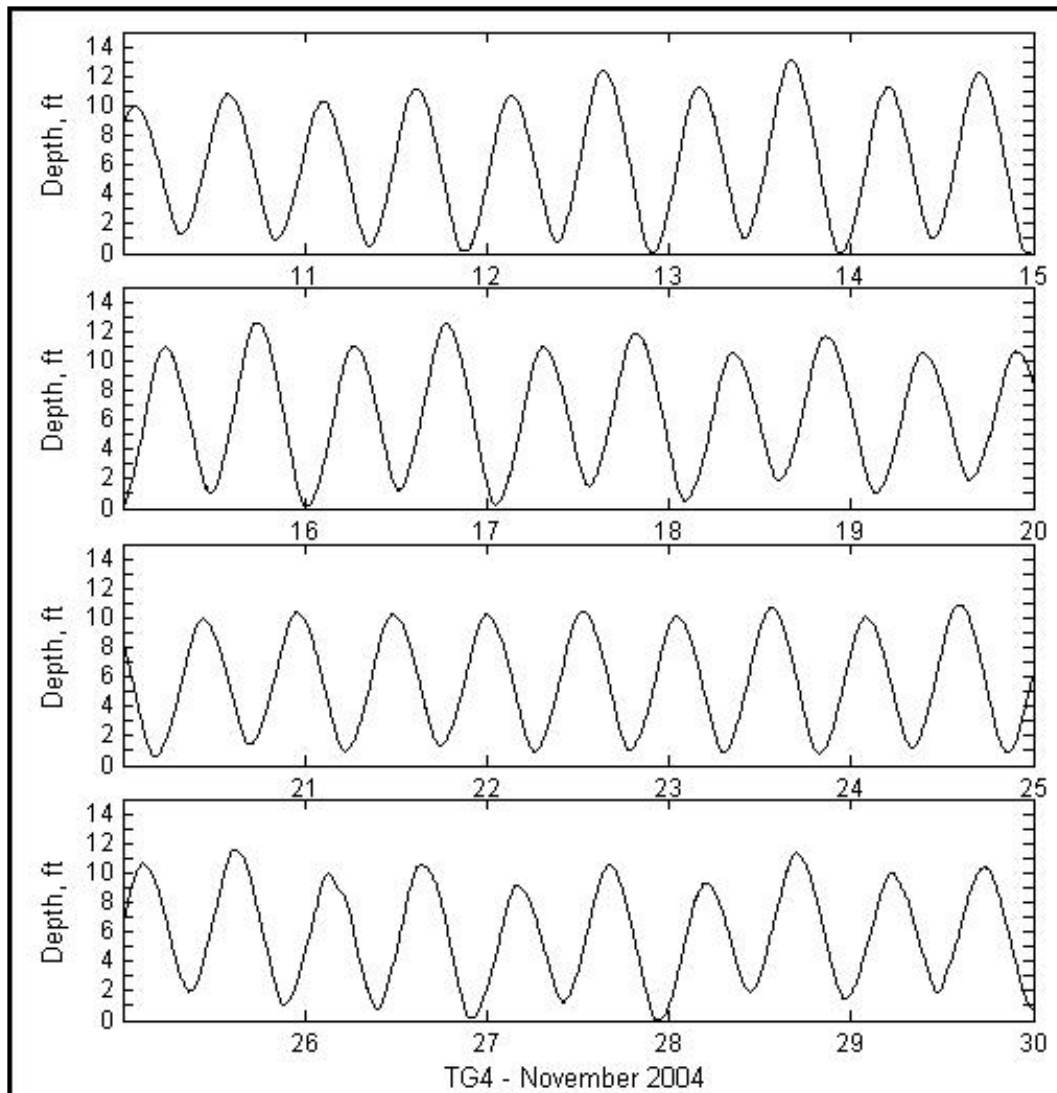
**TG4 Water-Level Measurement Plots**

Figure B21. TG4 water-level measurement plot, November 2004.

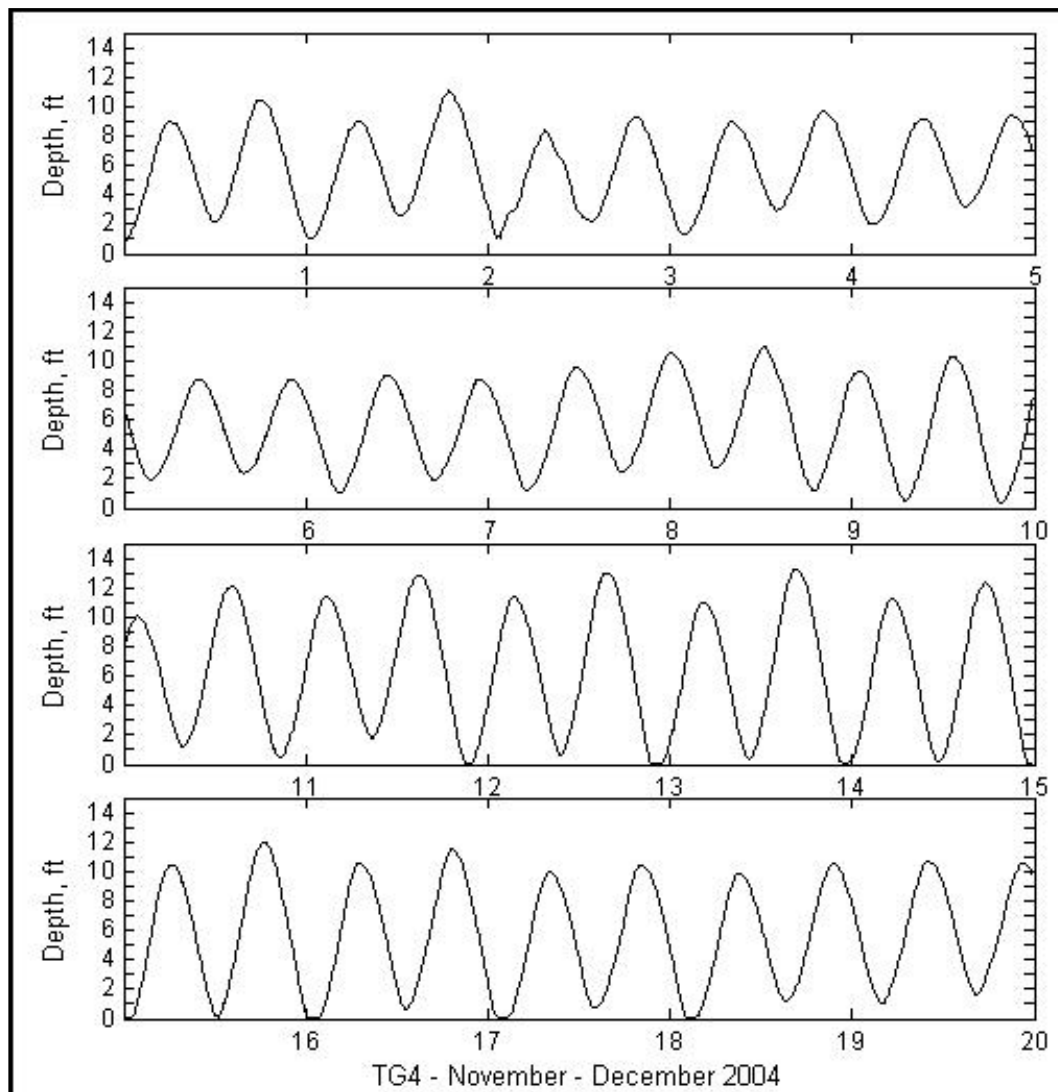


Figure B22. TG4 water-level measurement plot, November-December 2004.

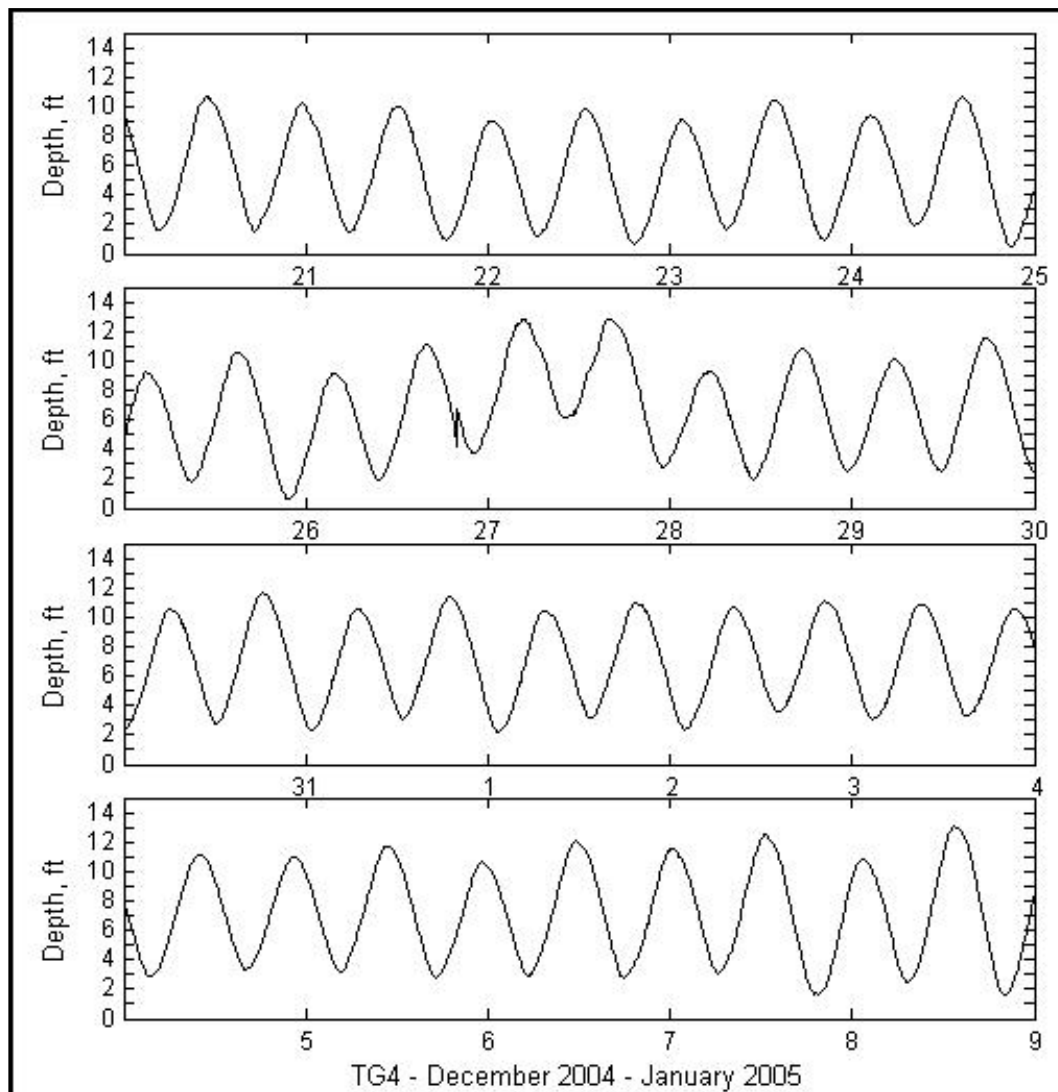


Figure B23. TG4 water-level measurement plot, December 2004–January 2005.

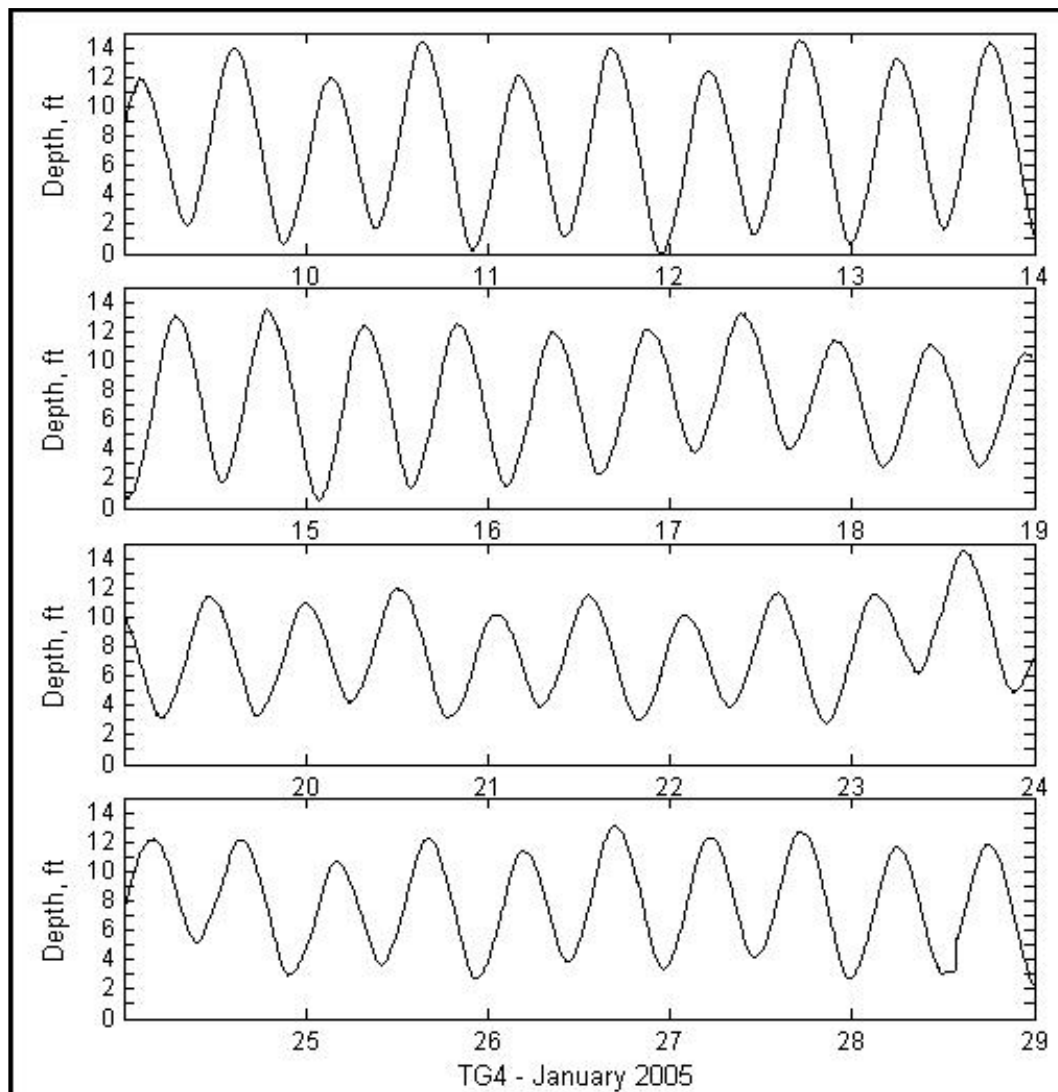


Figure B24. TG4 water-level measurement plot, January 2005.

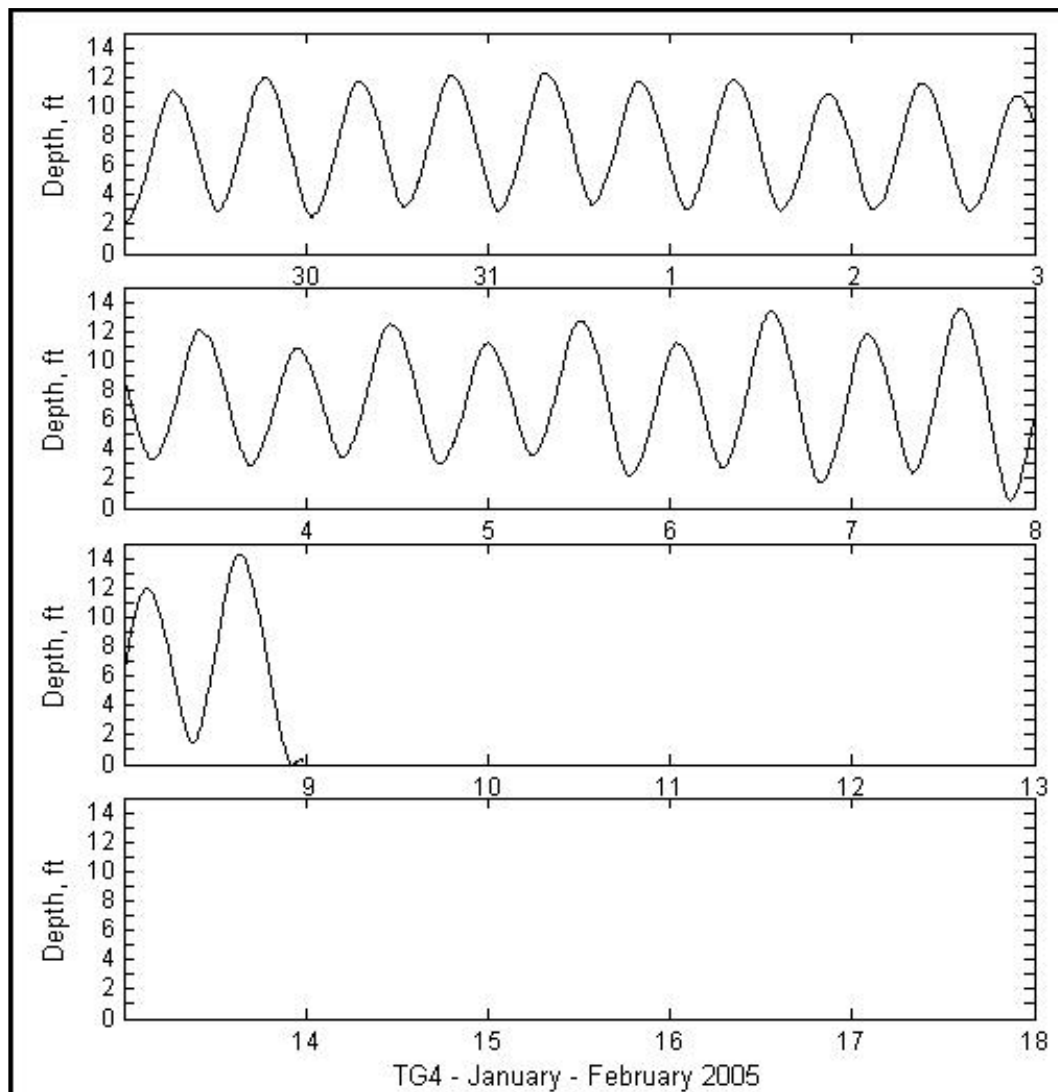


Figure B25. TG4 water-level measurement plot, January-February 2005.

## Appendix C: Moored Current Measurement Plots

### CM2 Moored Current Measurement Plots

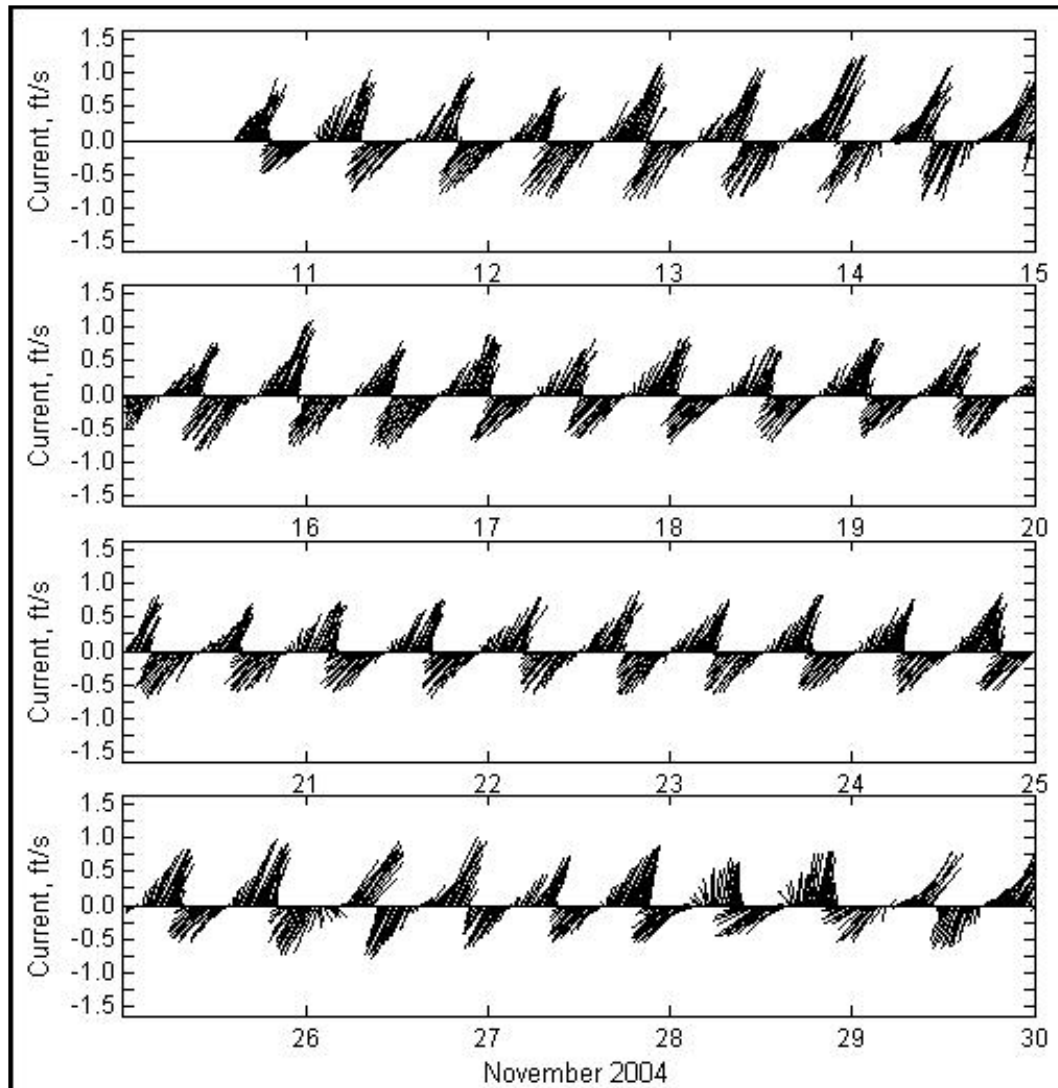


Figure C1. CM2 moored current measurement plots, November 2004.

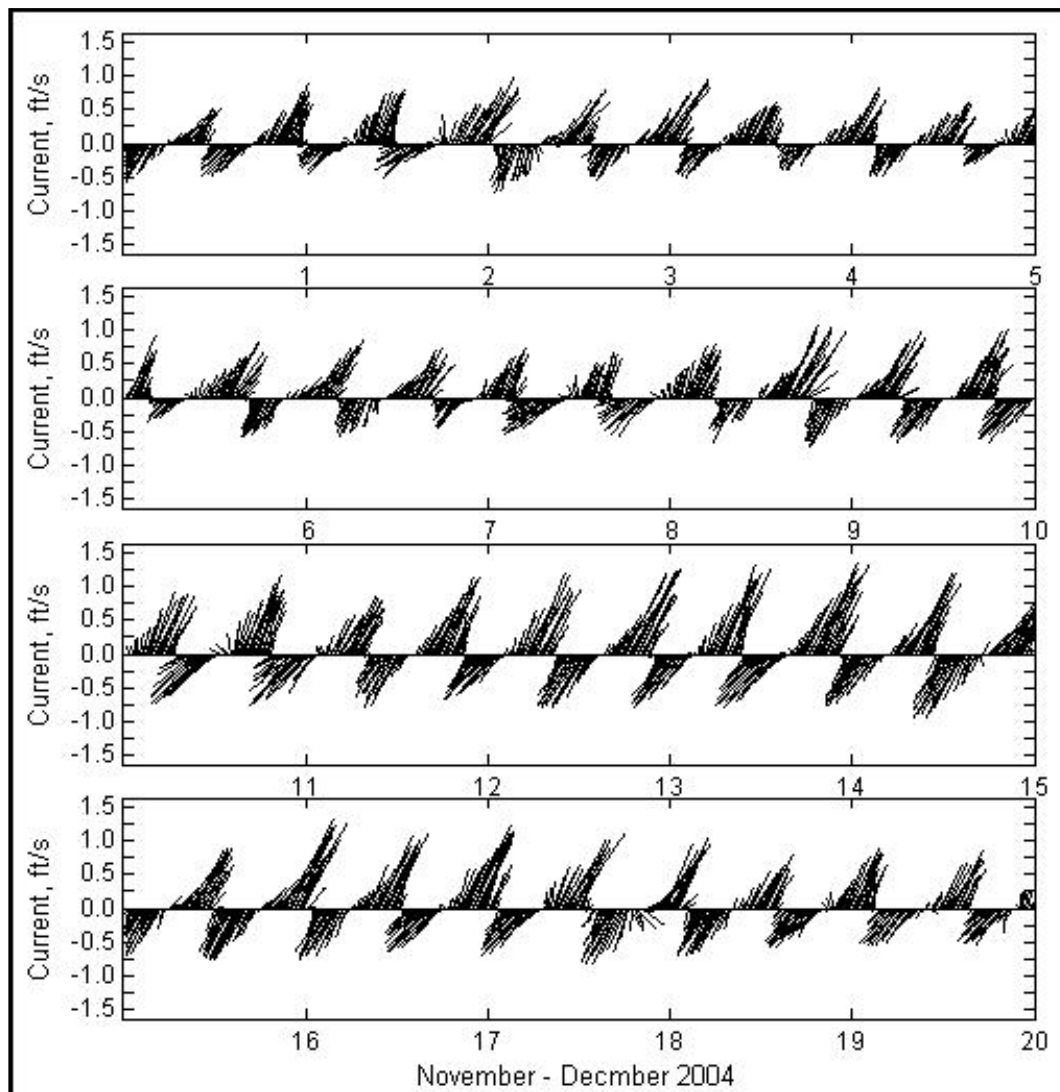


Figure C2. CM2 moored current measurement plots, November-December 2004.

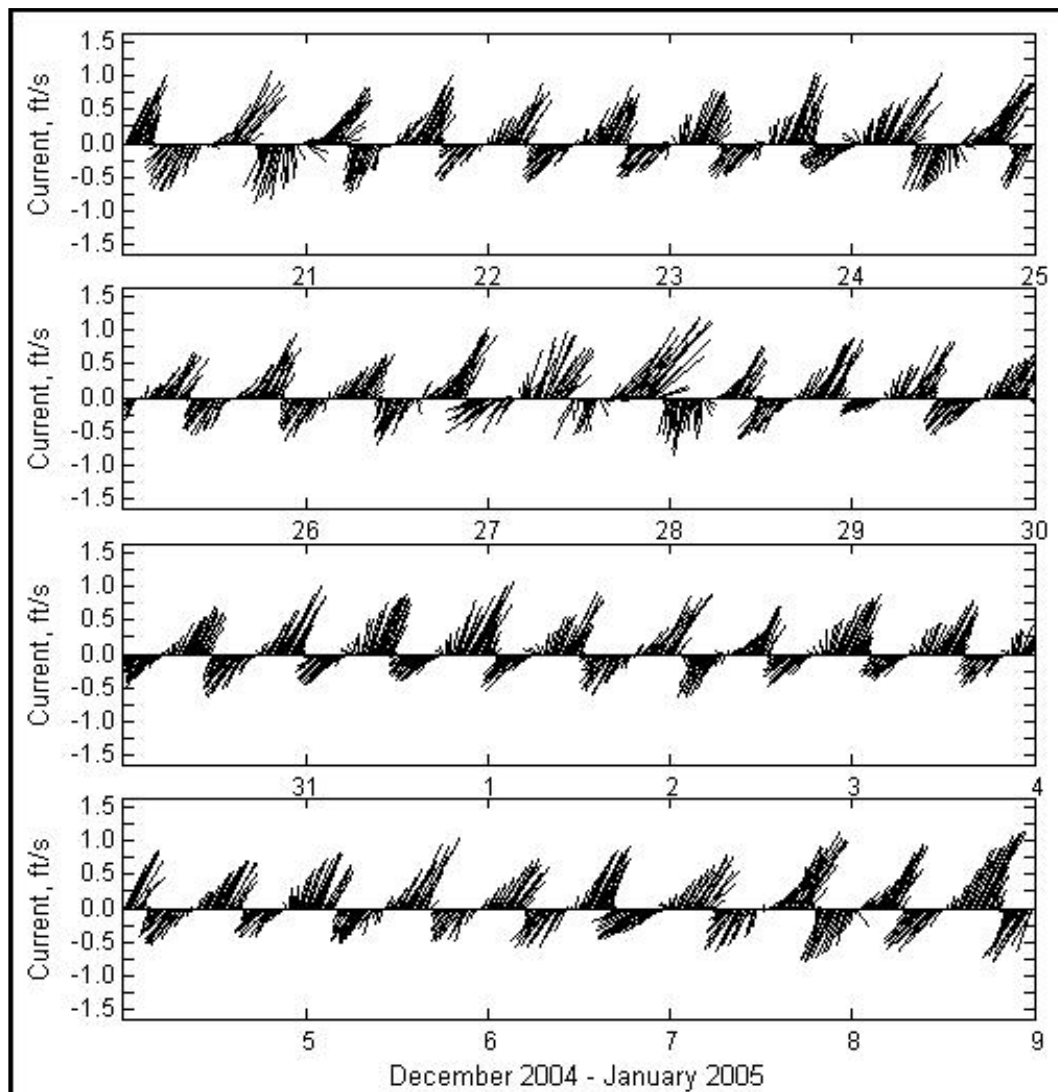


Figure C3. CM2 moored current measurement plots, December 2004–January 2005.

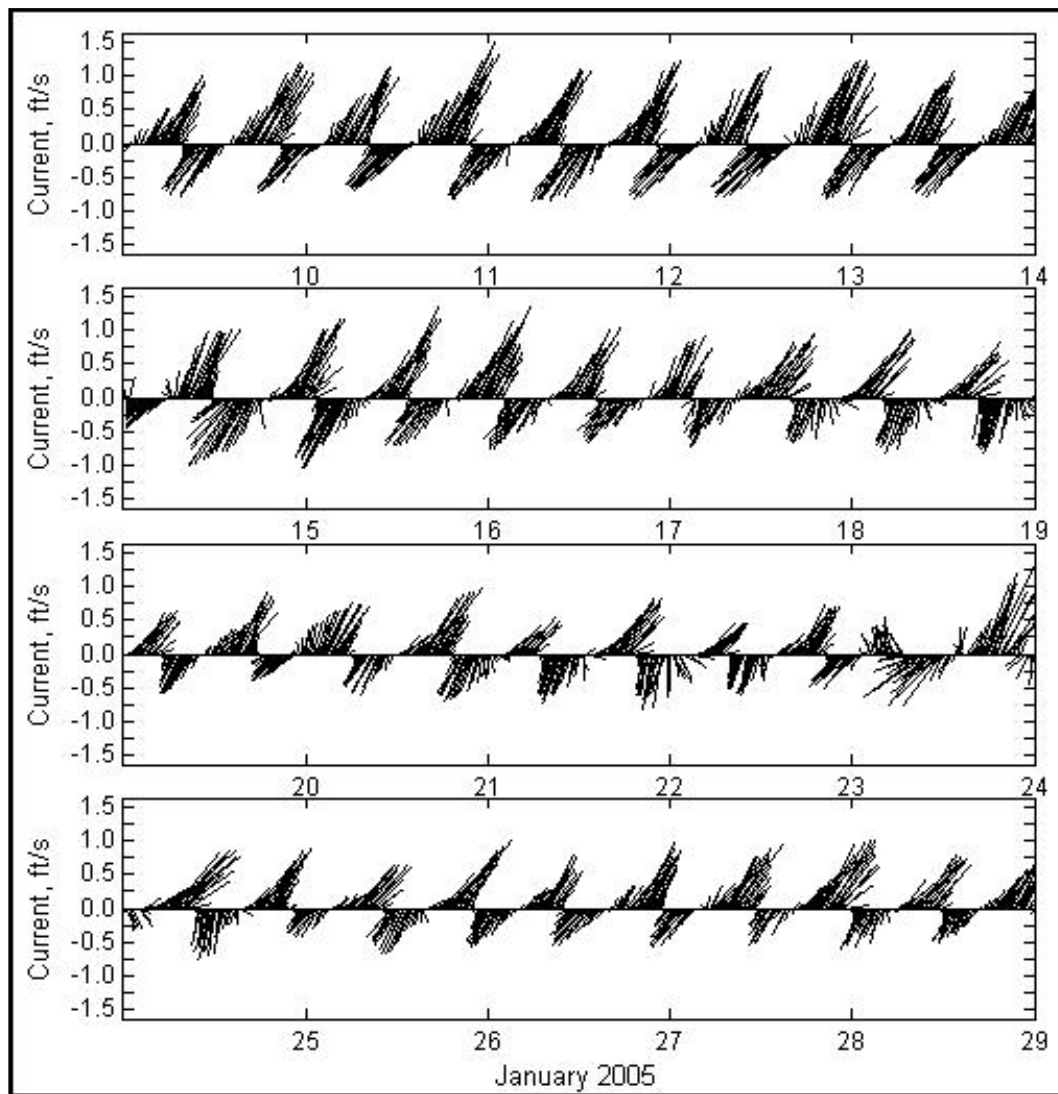


Figure C4. CM2 moored current measurement plots, January 2005.

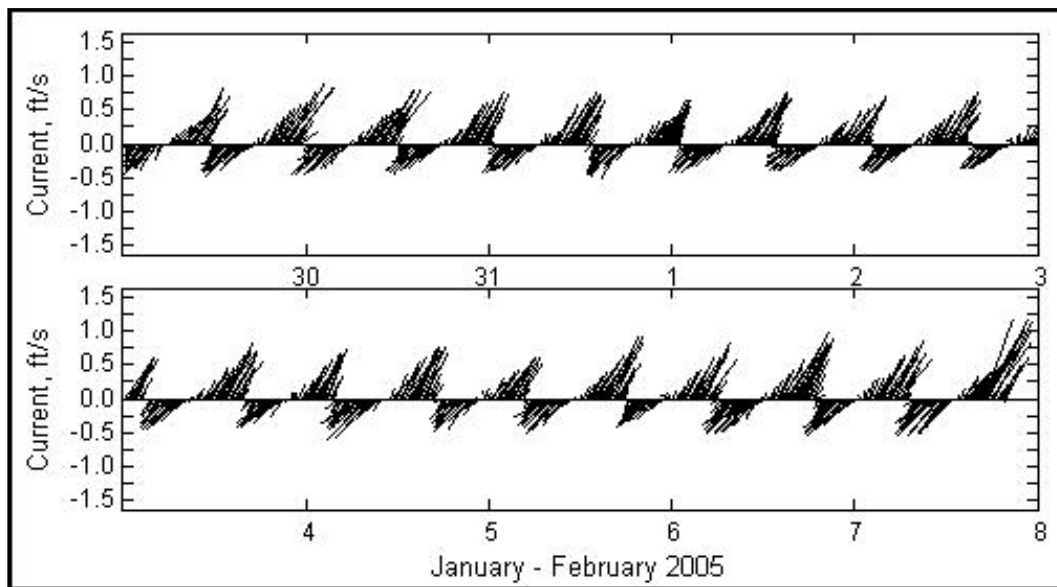


Figure C5. CM2 moored current measurement plots, January-February 2005.

## Appendix D: Transect Current Surveys, Depth-Averaged Current Plots

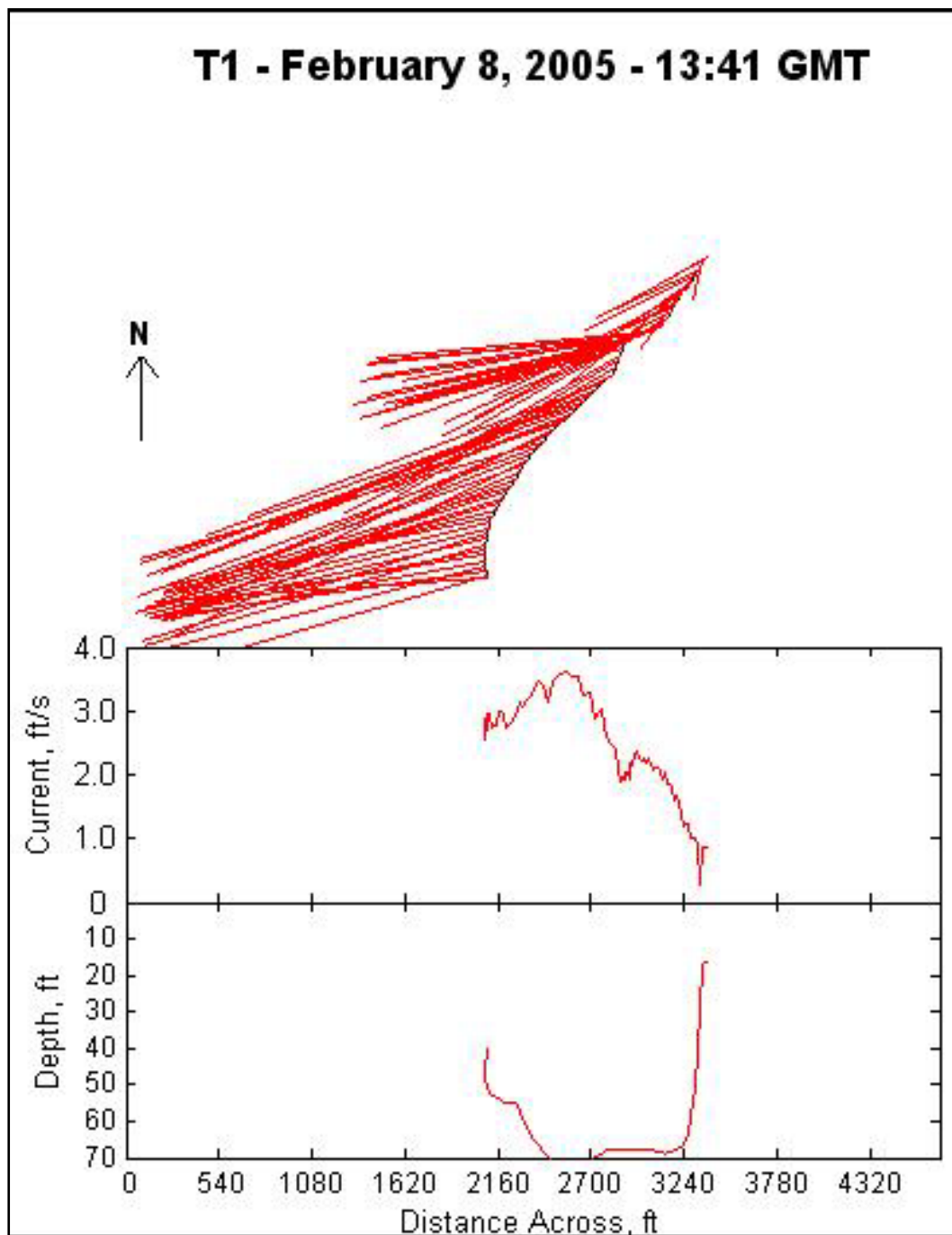


Figure D1. Transect 1 depth-averaged current plots, 8 February 2005, 1341 GMT.

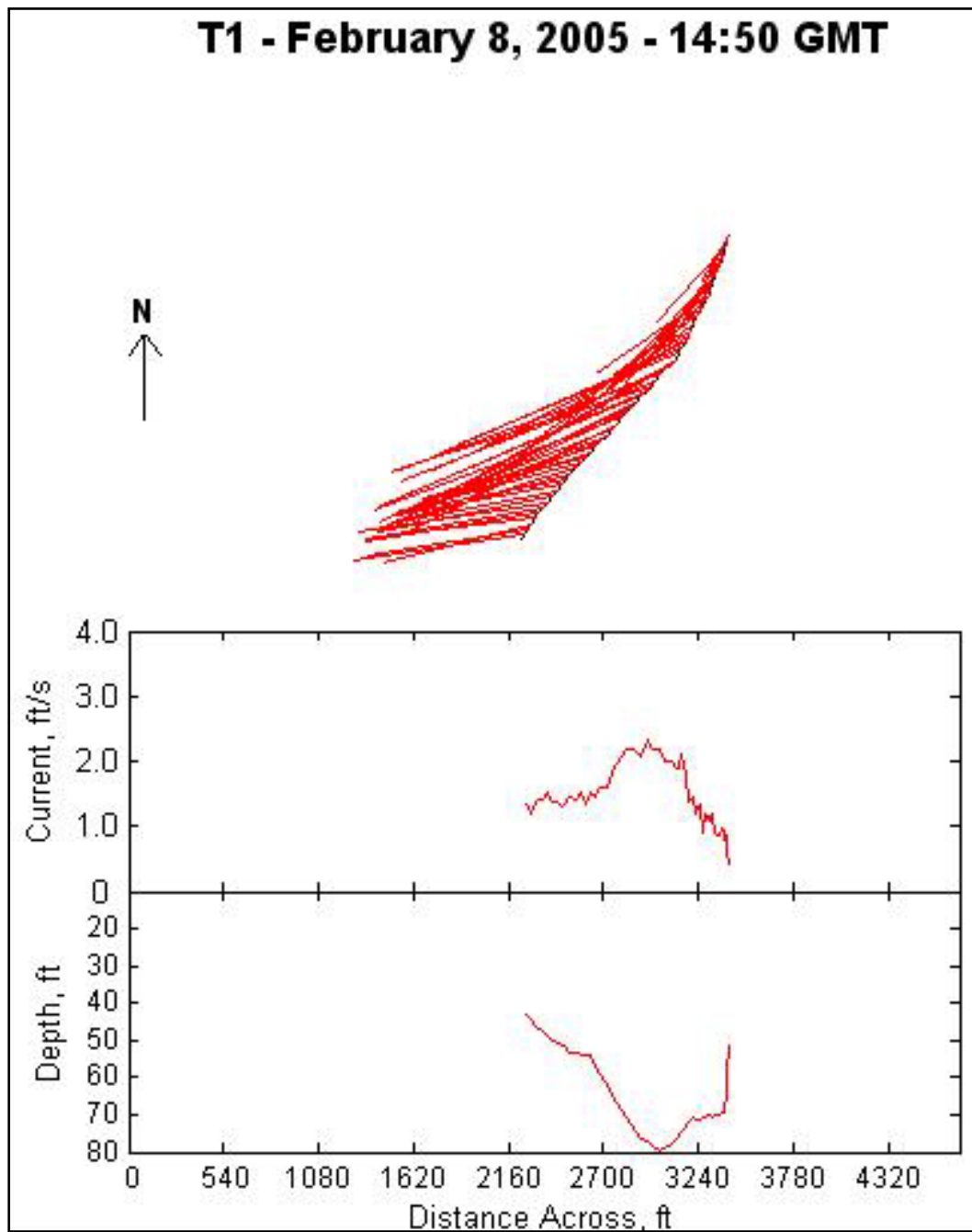


Figure D2. Transect 1 depth-averaged current plots, 8 February 2005, 1450 GMT.

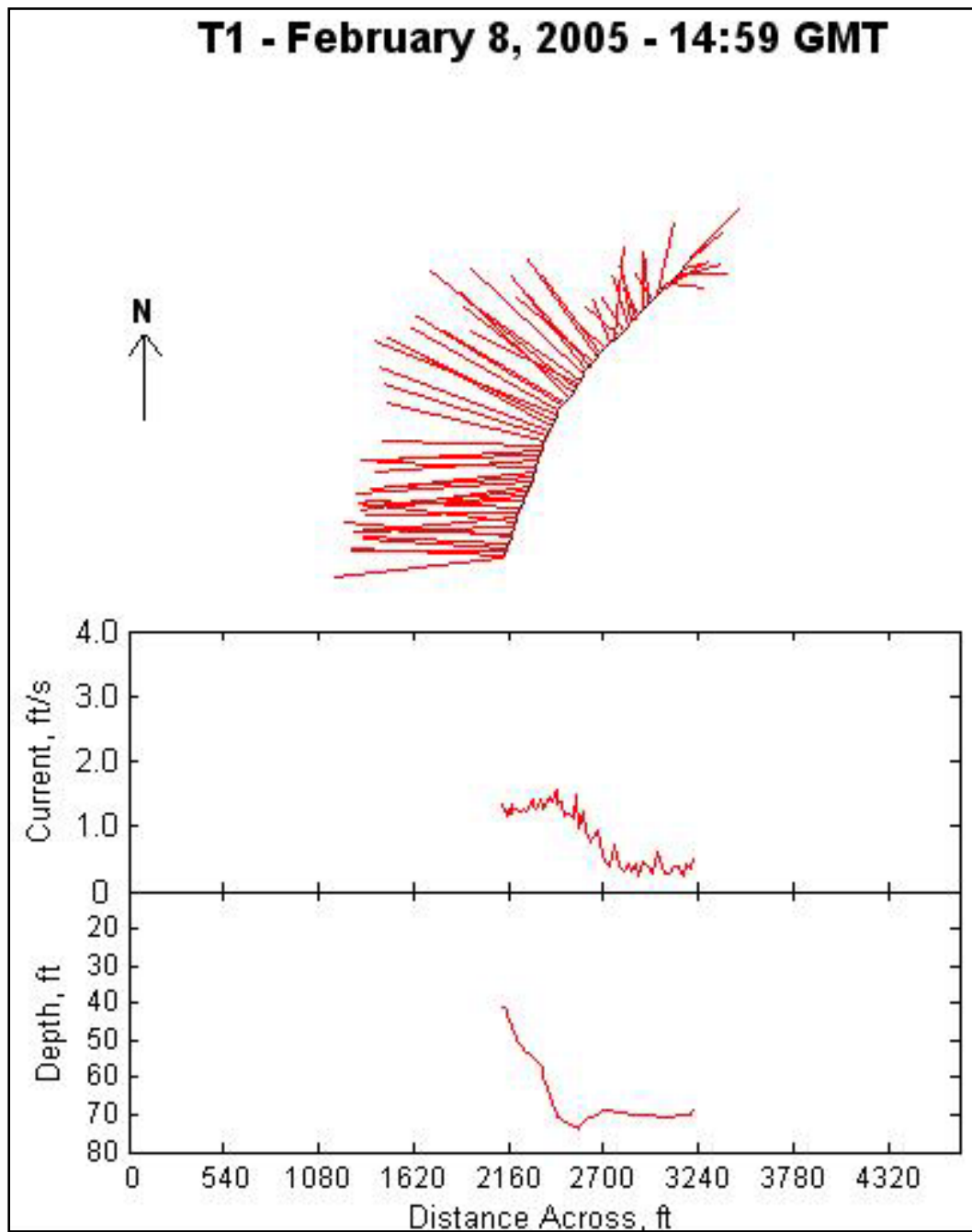


Figure D3. Transect 1 depth-averaged current plots, 8 February 2005, 1459 GMT.

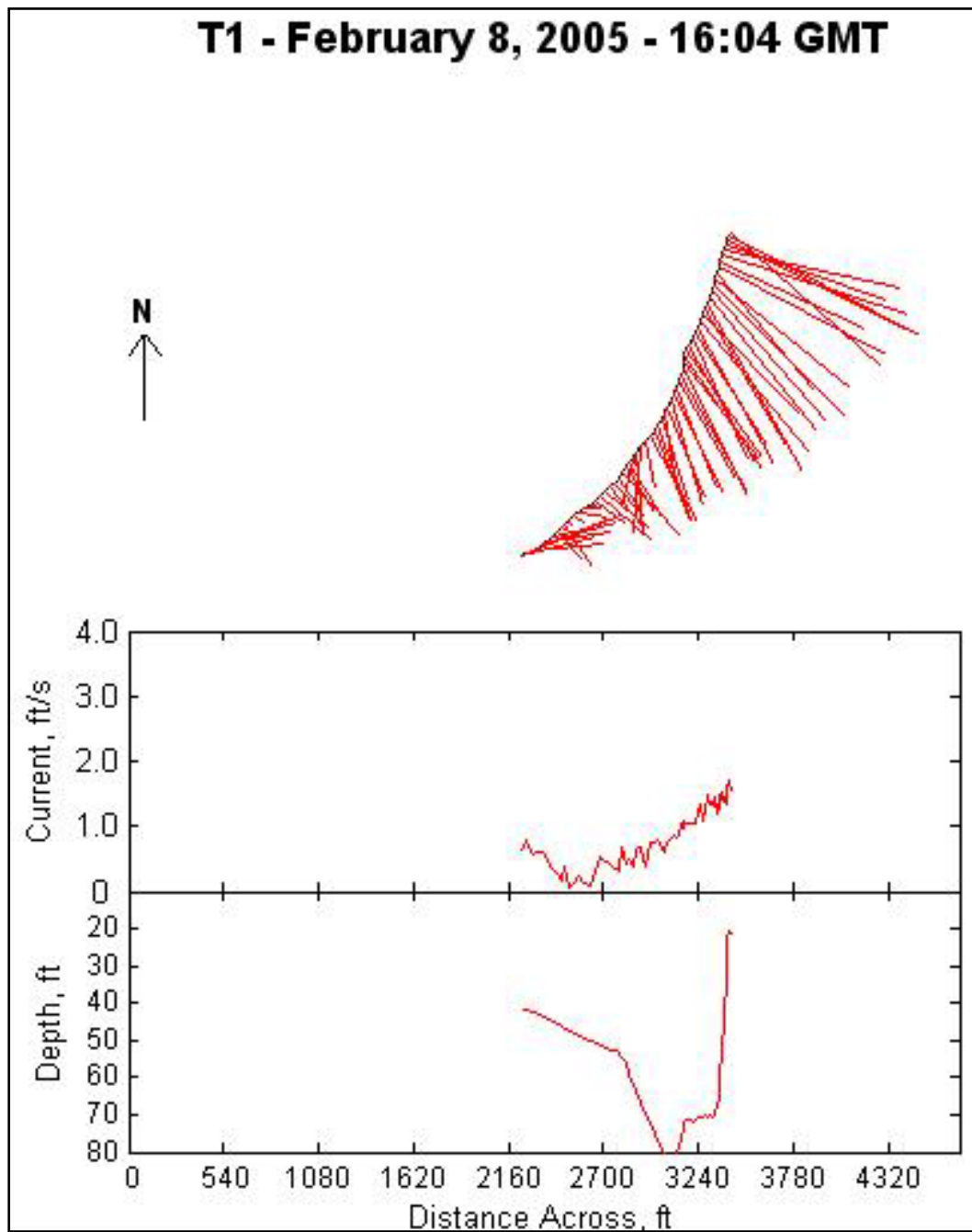


Figure D4. Transect 1 depth-averaged current plots, 8 February 2005, 1604 GMT.

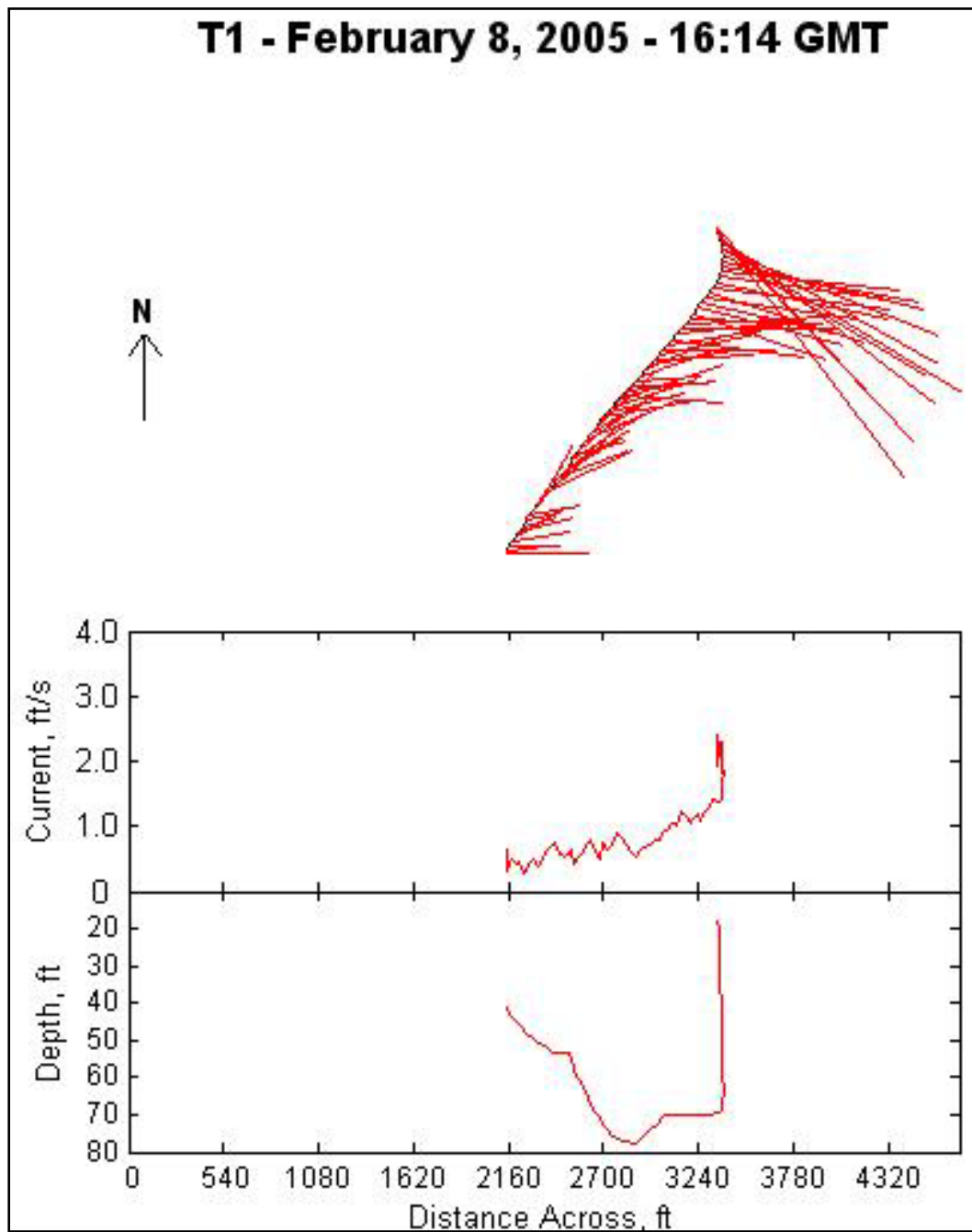


Figure D5. Transect 1 depth-averaged current plots, 8 February 2005, 1614 GMT.

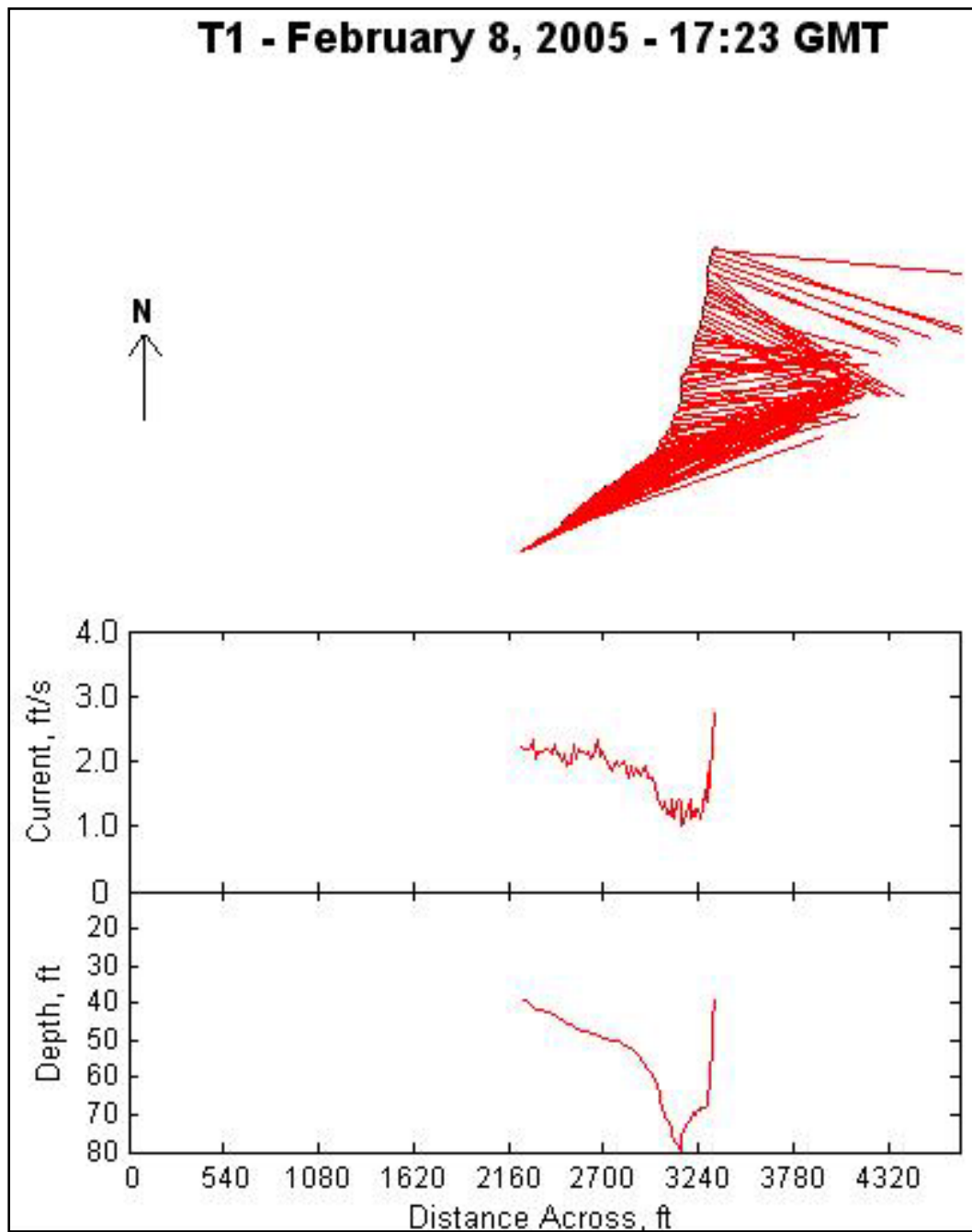


Figure D6. Transect 1 depth-averaged current plots, 8 February 2005, 1723 GMT.

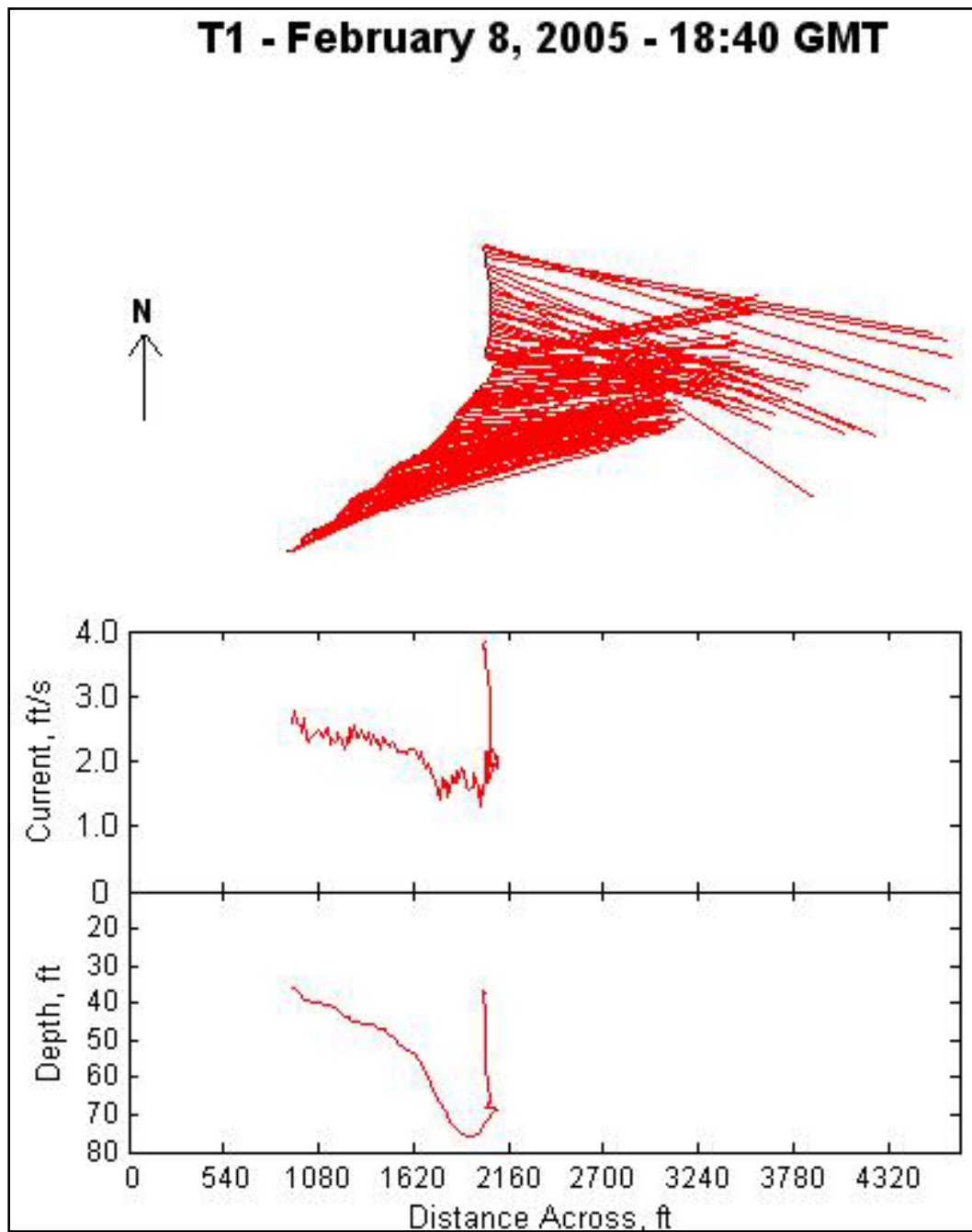


Figure D7. Transect 1 depth-averaged current plots, 8 February 2005, 1840 GMT.

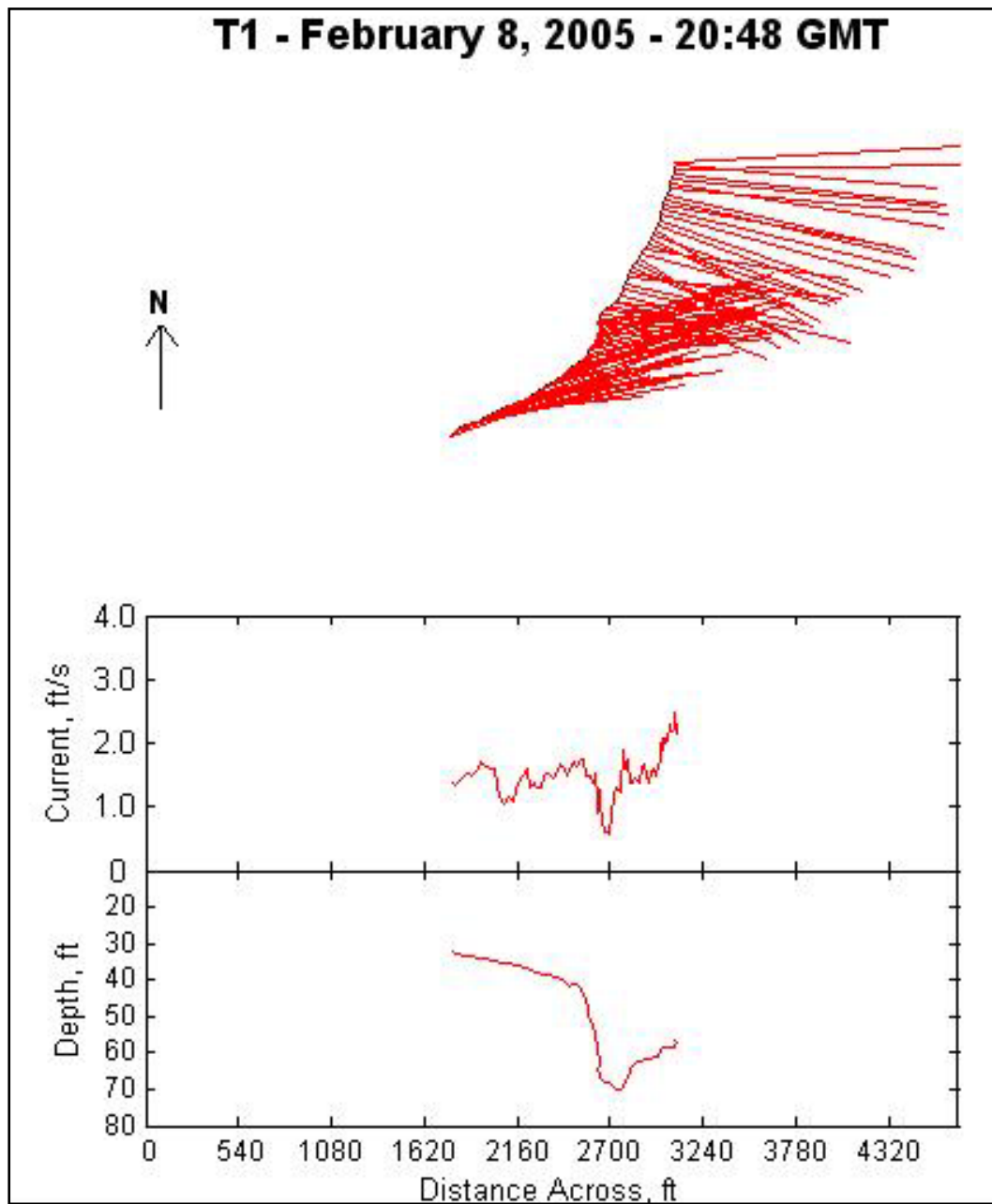


Figure D8. Transect 1 depth-averaged current plots, 8 February 2005, 2048 GMT.

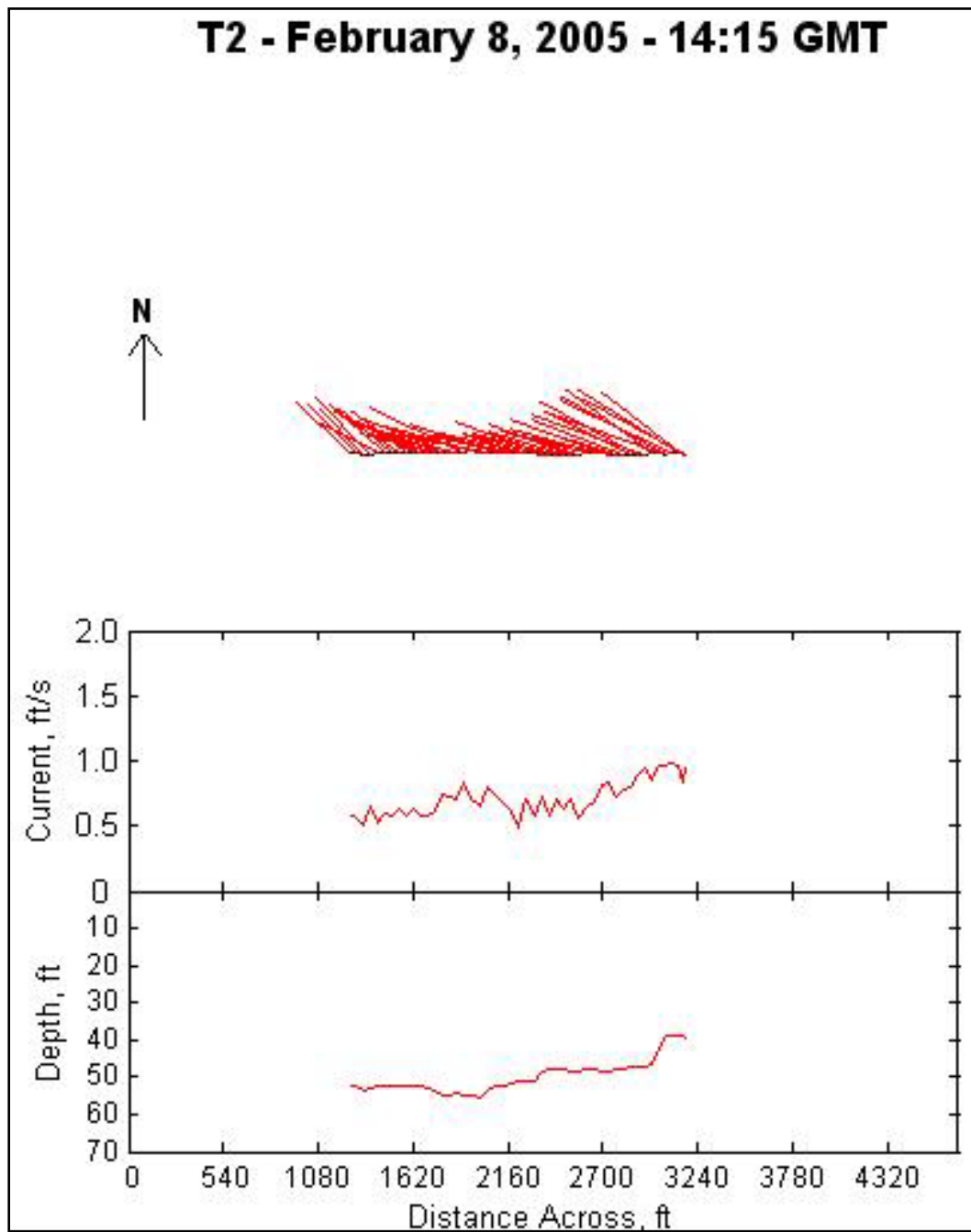


Figure D9. Transect 2 depth-averaged current plots, 8 February 2005, 1415 GMT.

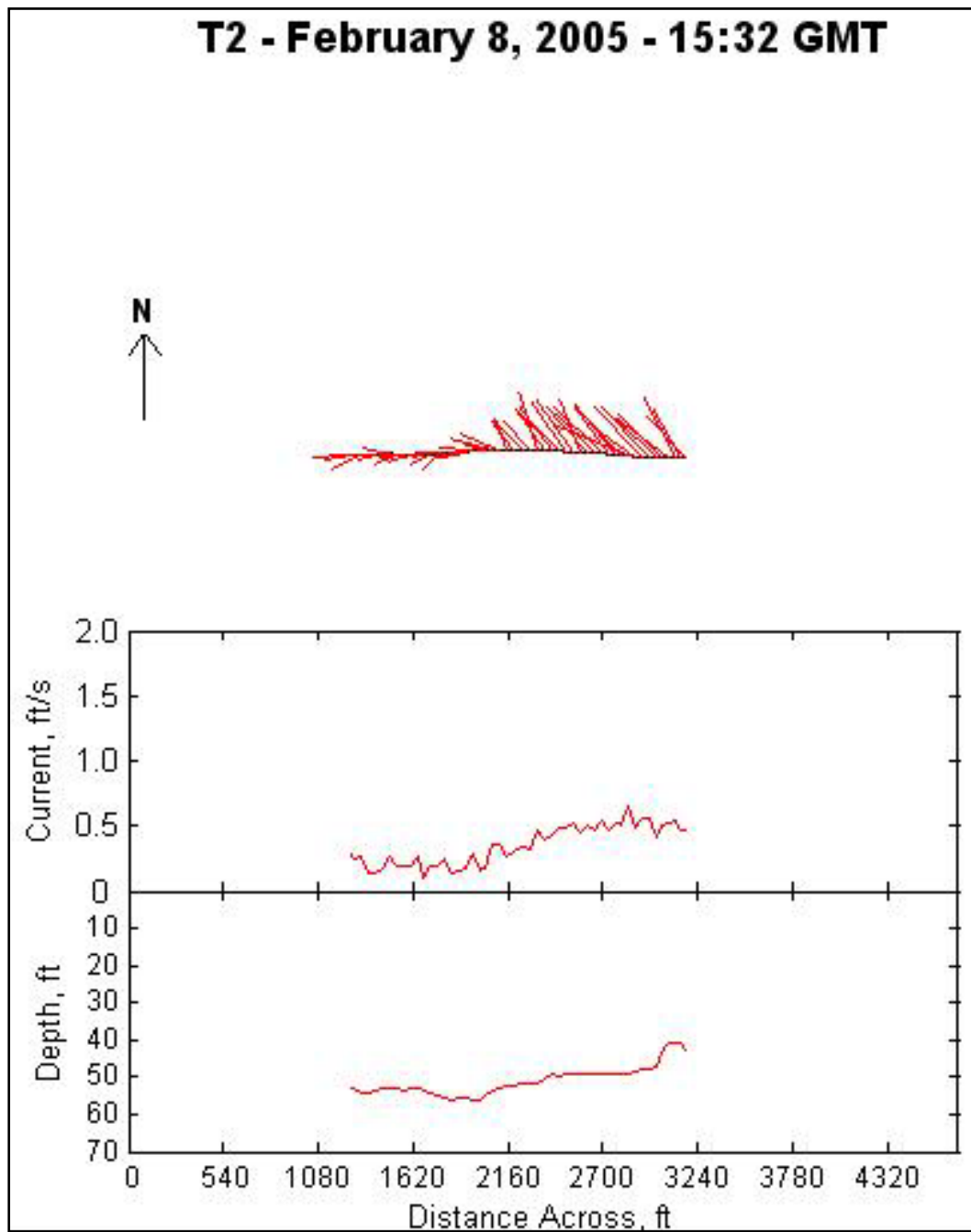


Figure D10. Transect 2 depth-averaged current plots, 8 February 2005, 1532 GMT.

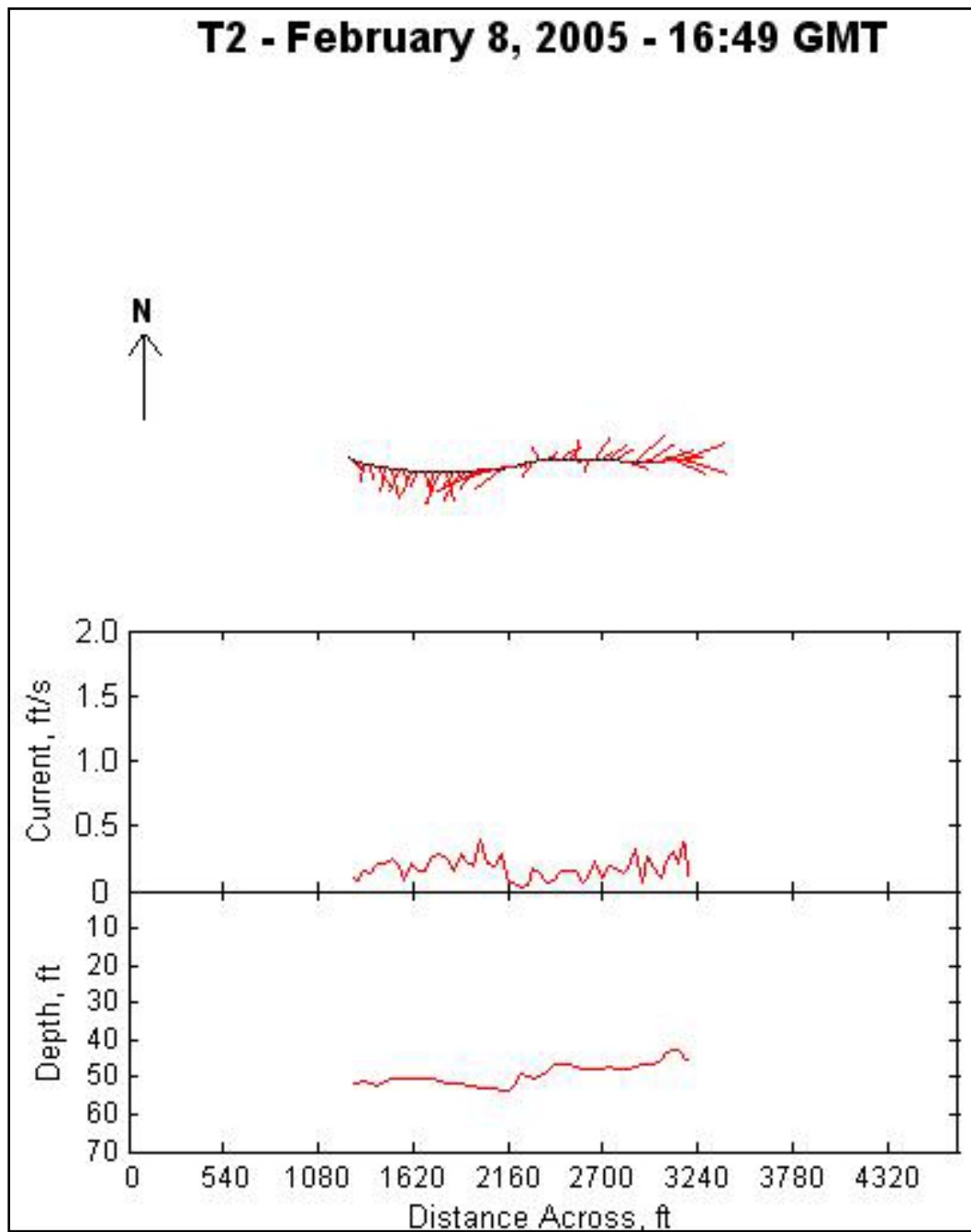


Figure D11. Transect 2 depth-averaged current plots, 8 February 2005, 1649 GMT.

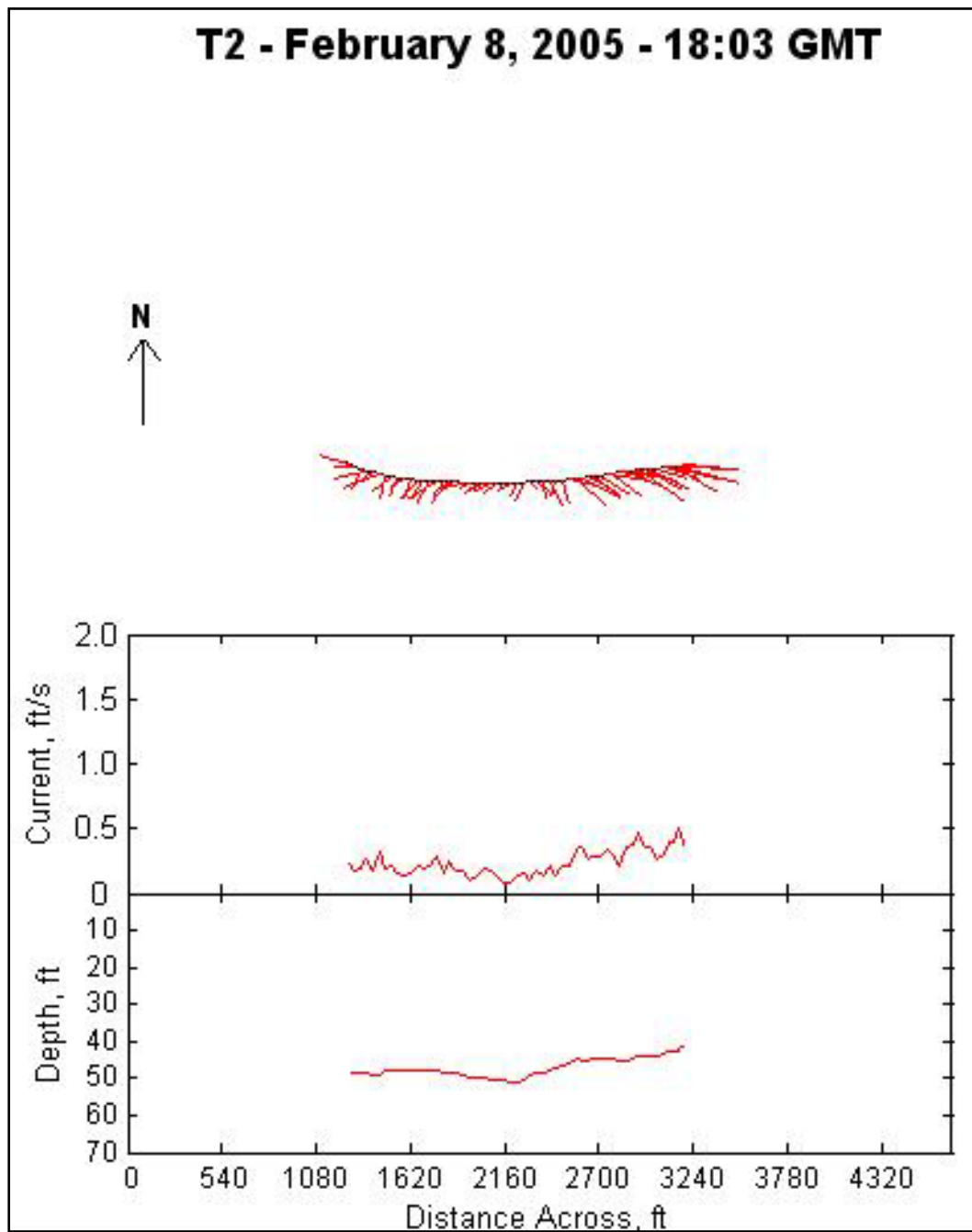


Figure D12. Transect 2 depth-averaged current plots, 8 February 2005, 1803 GMT.

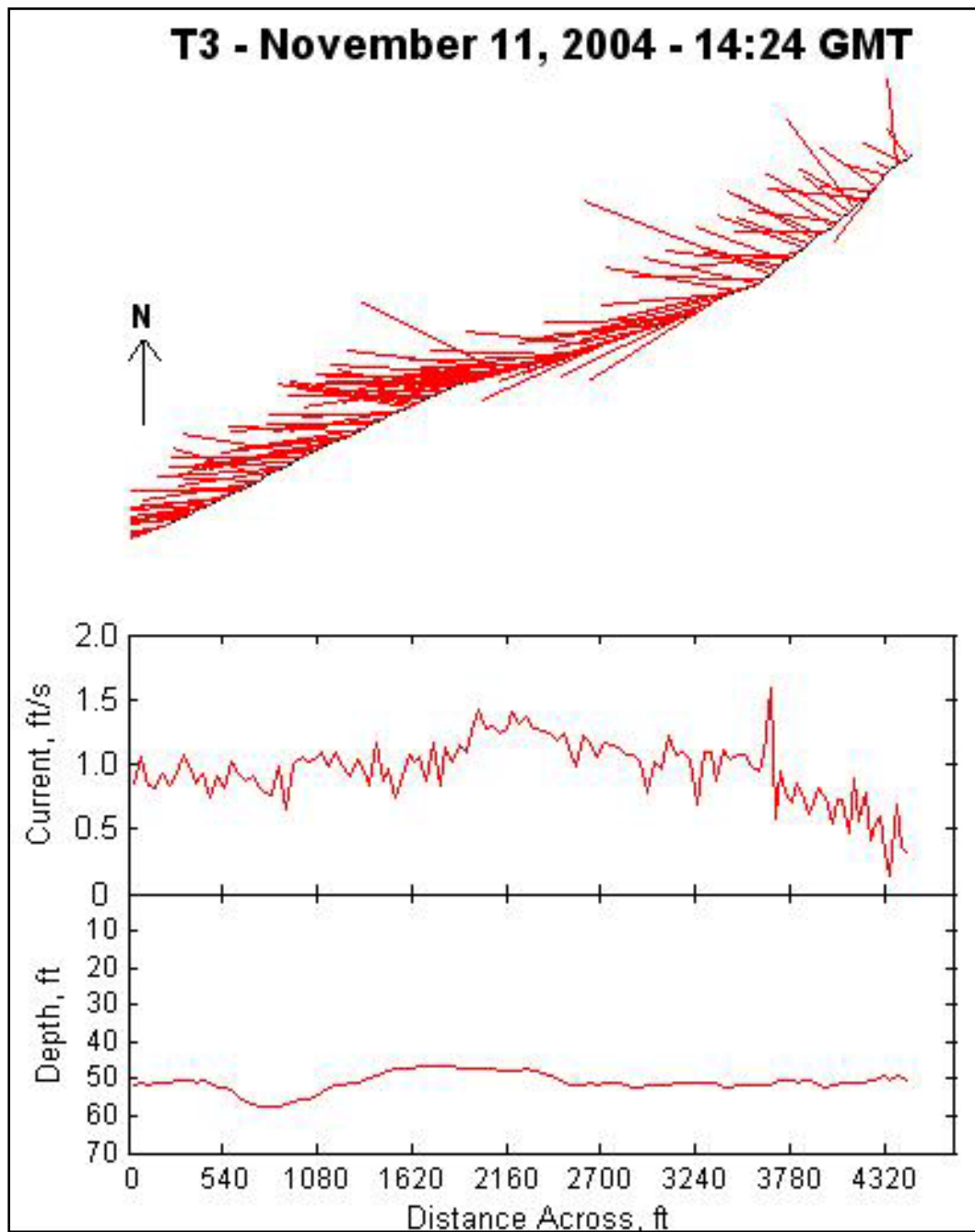


Figure D13. Transect 3 depth-averaged current plots, 11 November 2004, 1424 GMT.

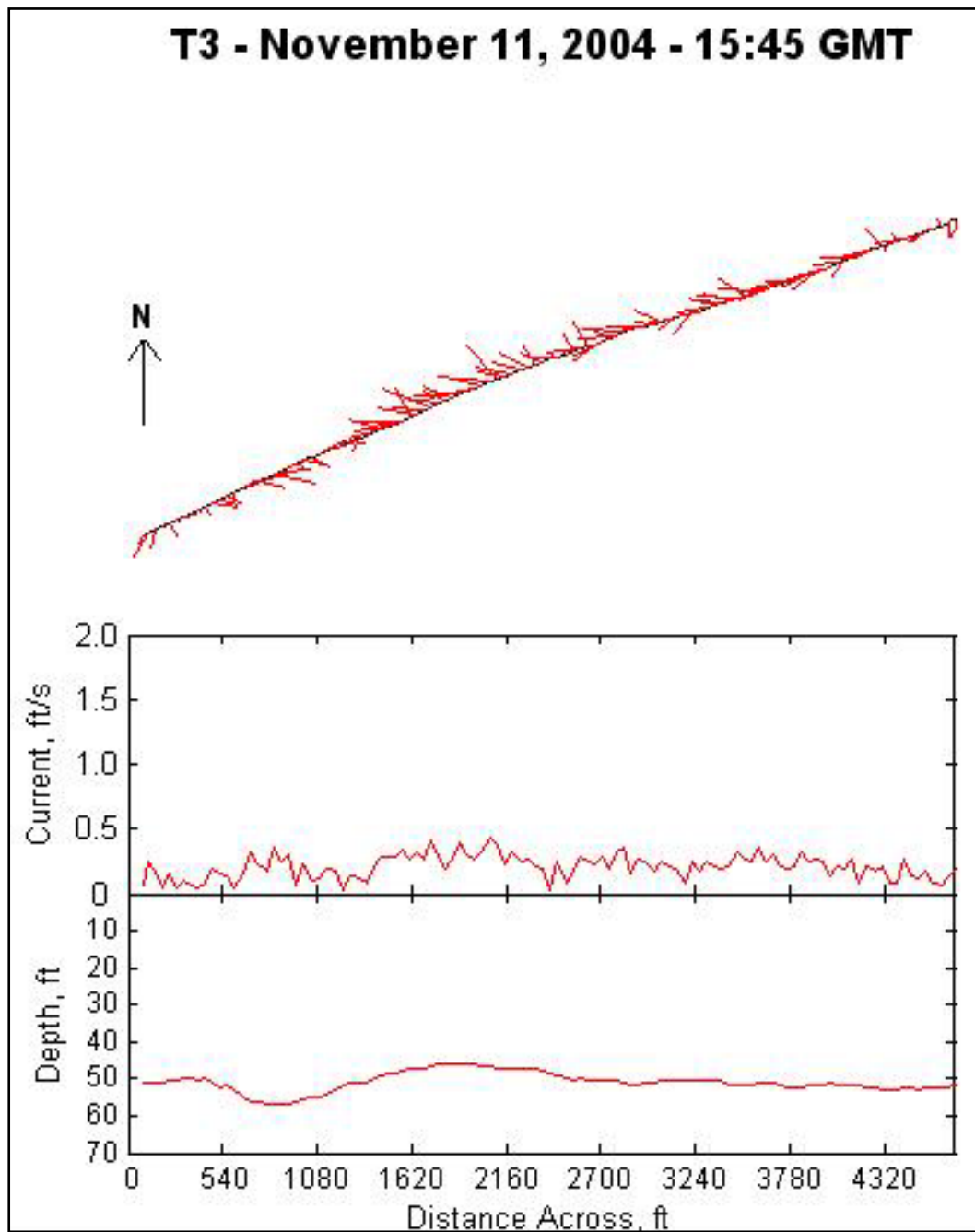


Figure D14. Transect 3 depth-averaged current plots, 11 November 2004, 1545 GMT.

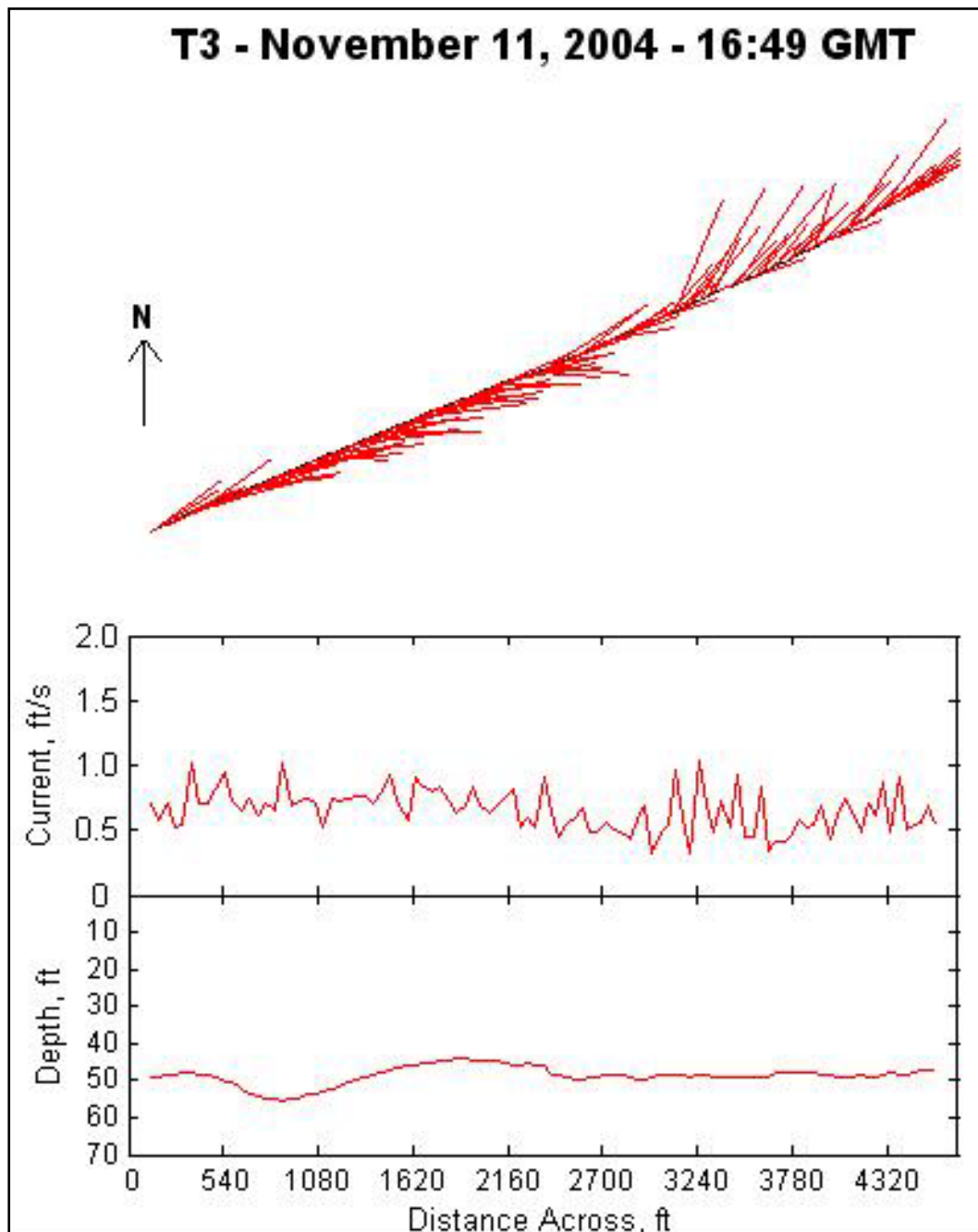


Figure D15. Transect 3 depth-averaged current plots, 11 November 2004, 1649 GMT.

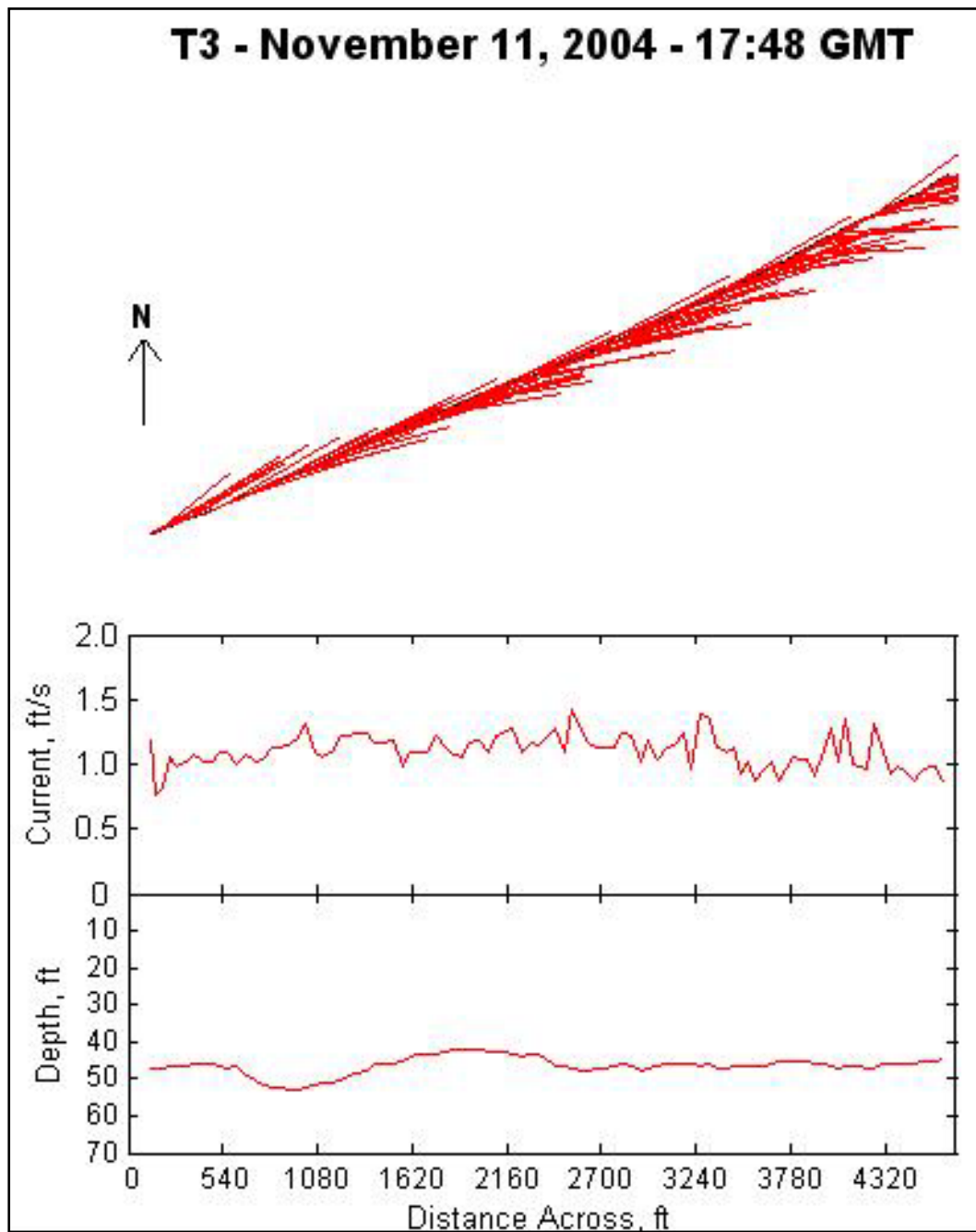


Figure D16. Transect 3 depth-averaged current plots, 11 November 2004, 1748 GMT.

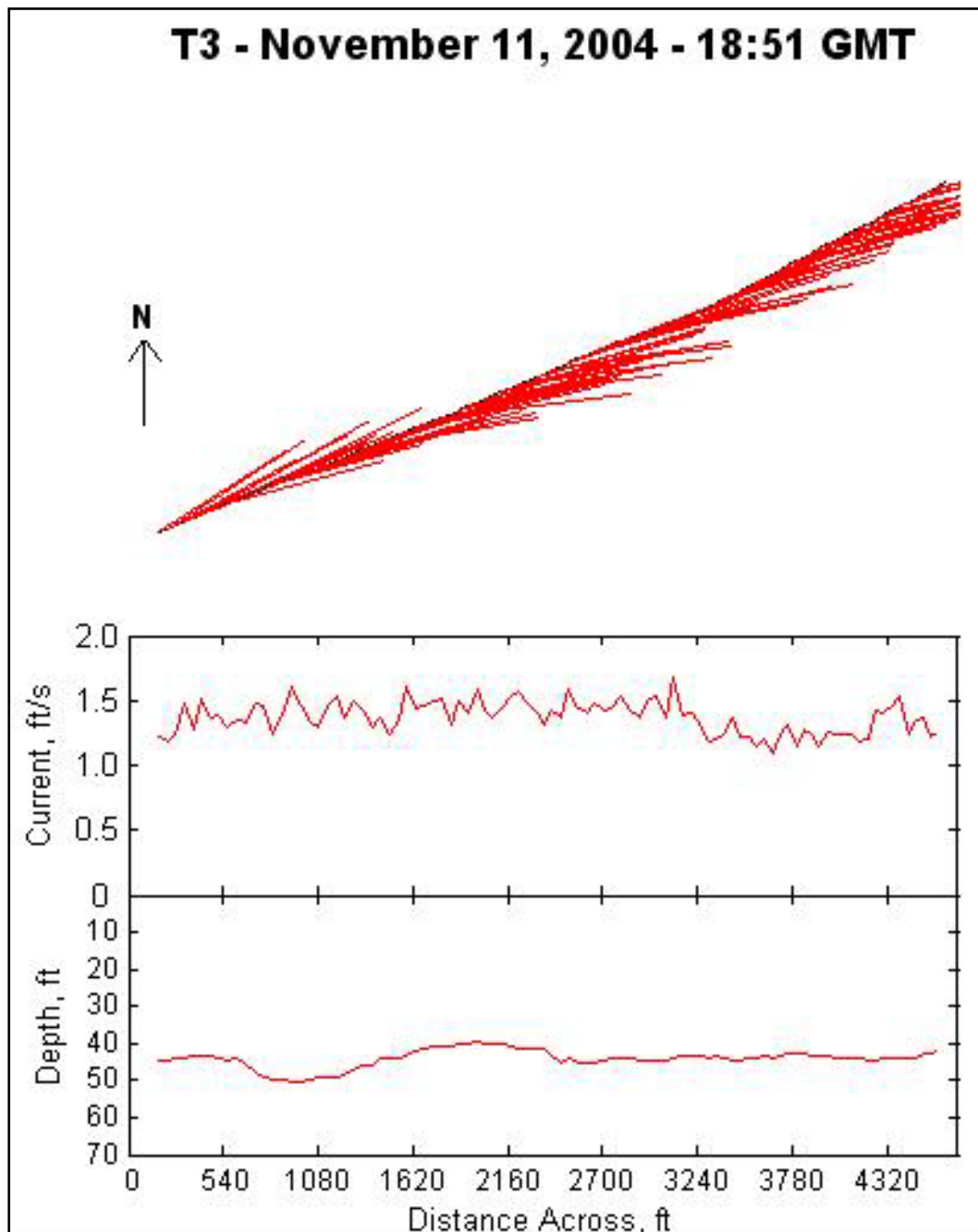


Figure D17. Transect 3 depth-averaged current plots, 11 November 2004, 1851 GMT.

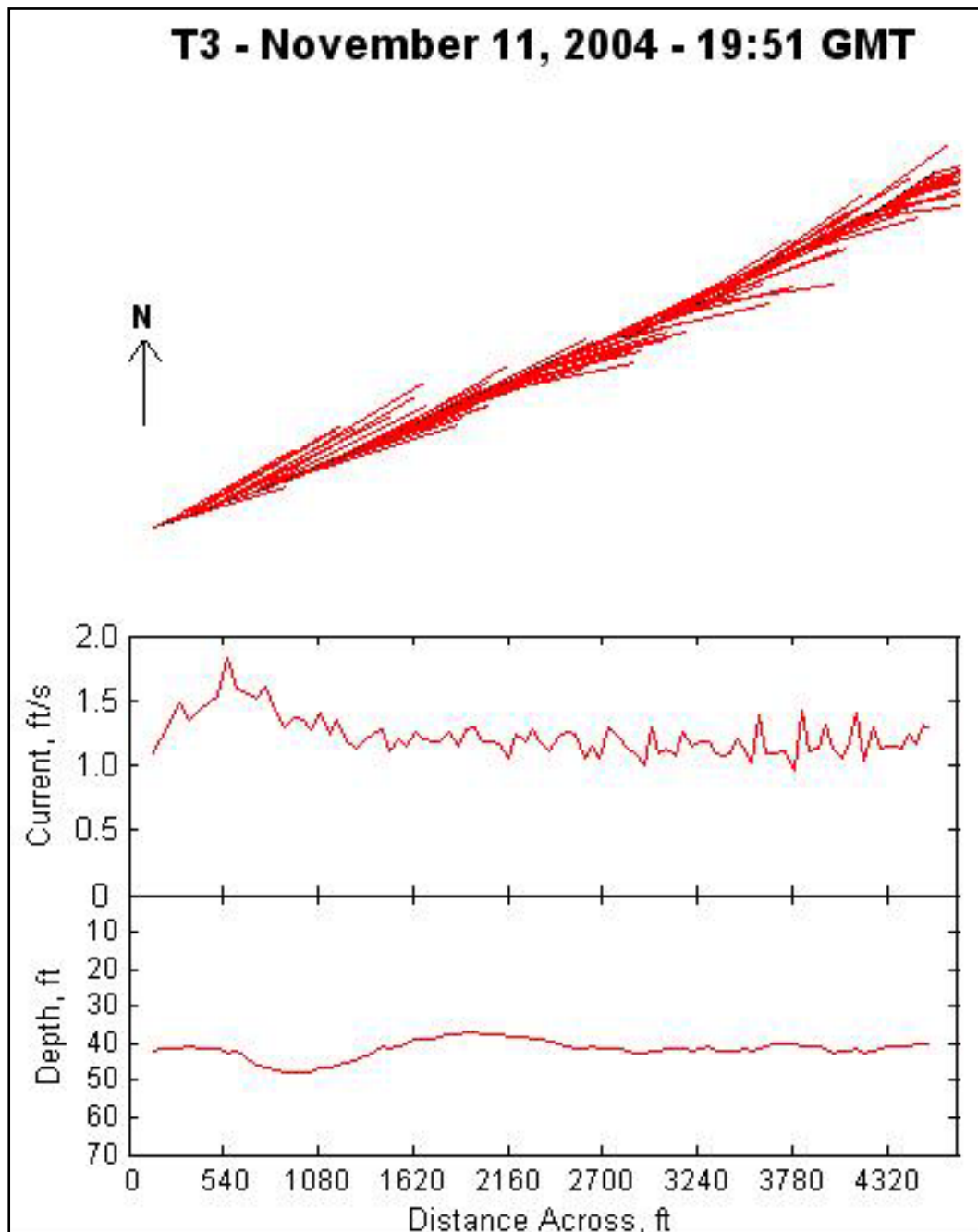


Figure D18. Transect 3 depth-averaged current plots, 11 November 2004, 1951 GMT.

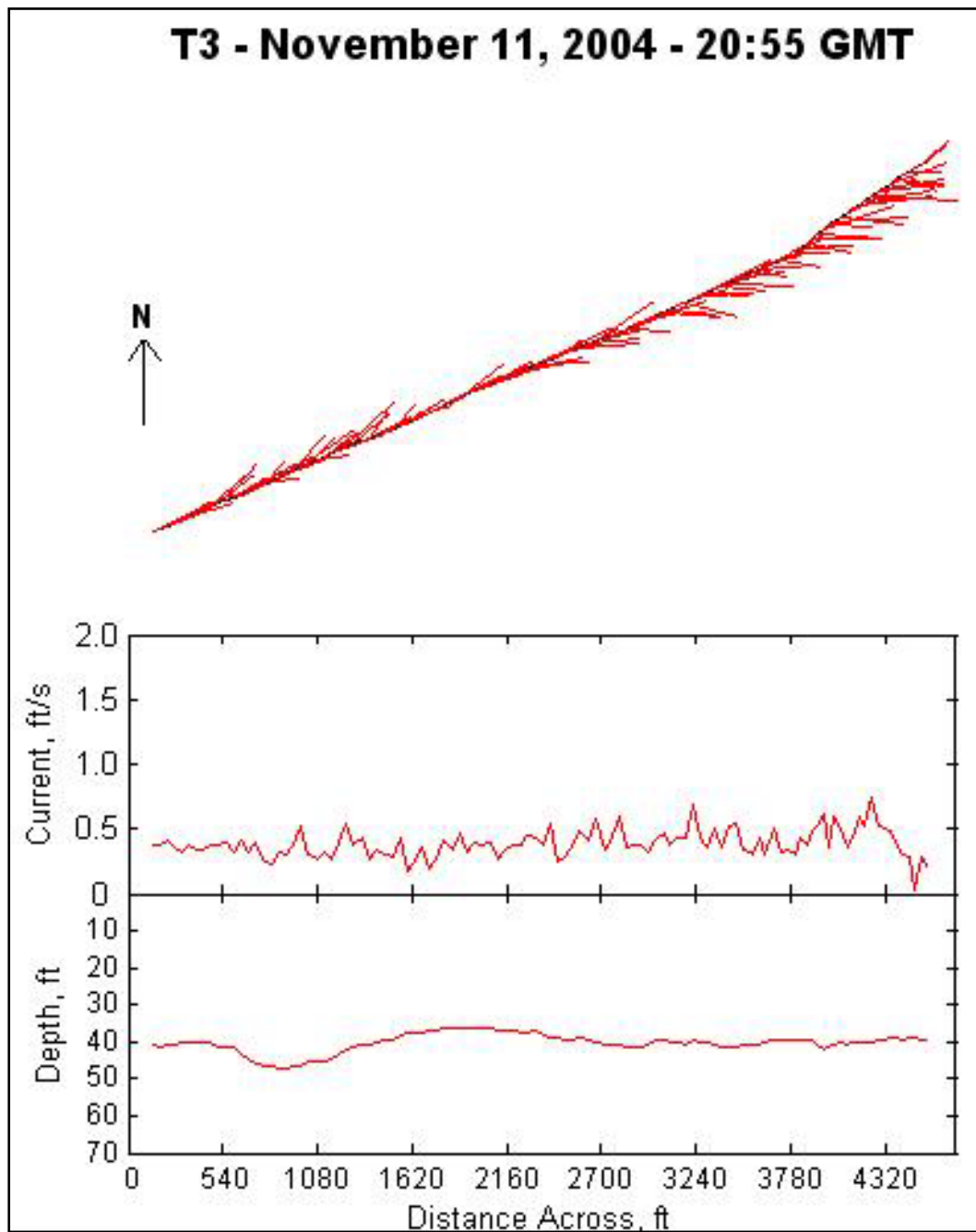


Figure D19. Transect 3 depth-averaged current plots, 11 November 2004, 2055 GMT.

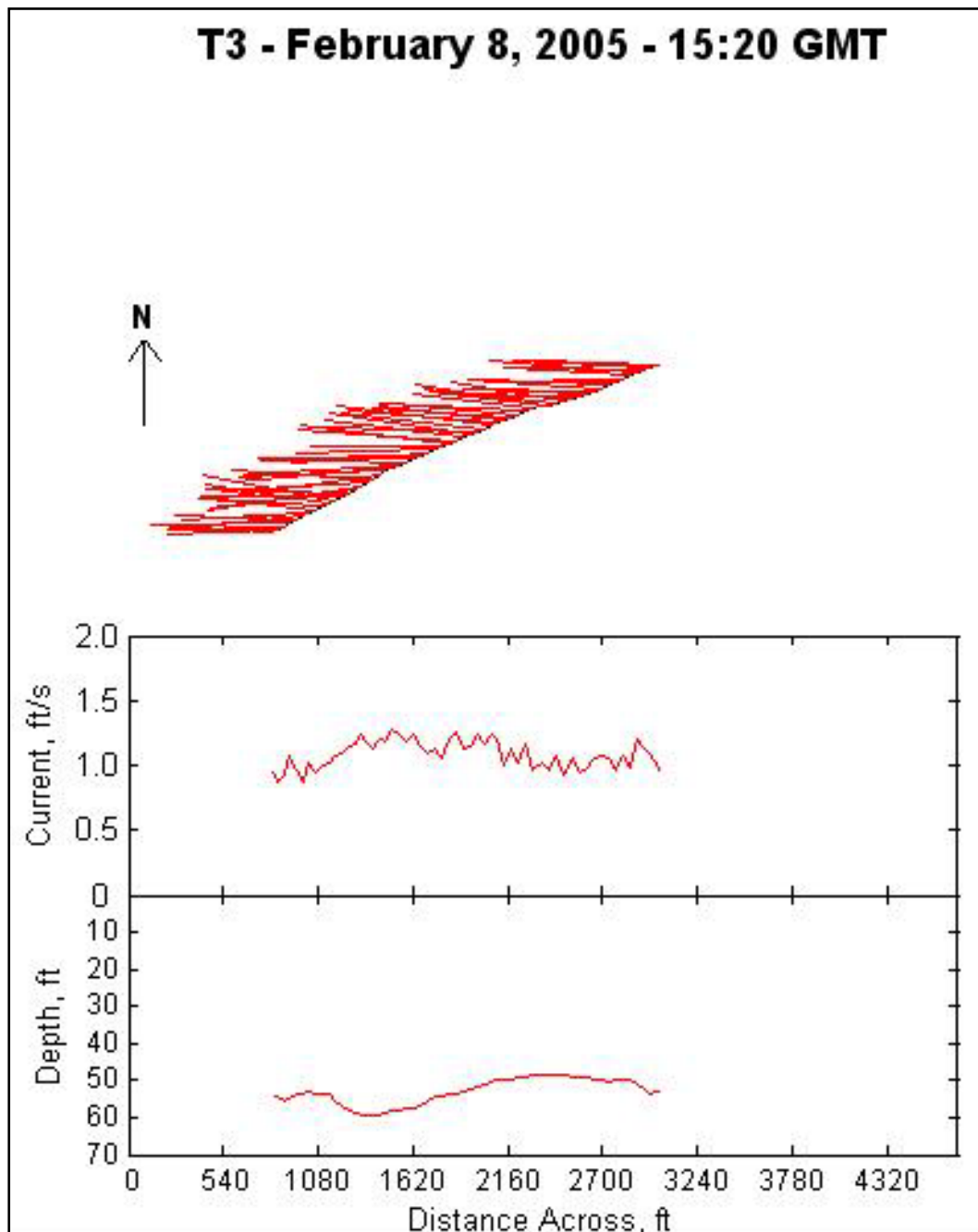


Figure D20. Transect 3 depth-averaged current plots, 8 February 2005, 1520 GMT.

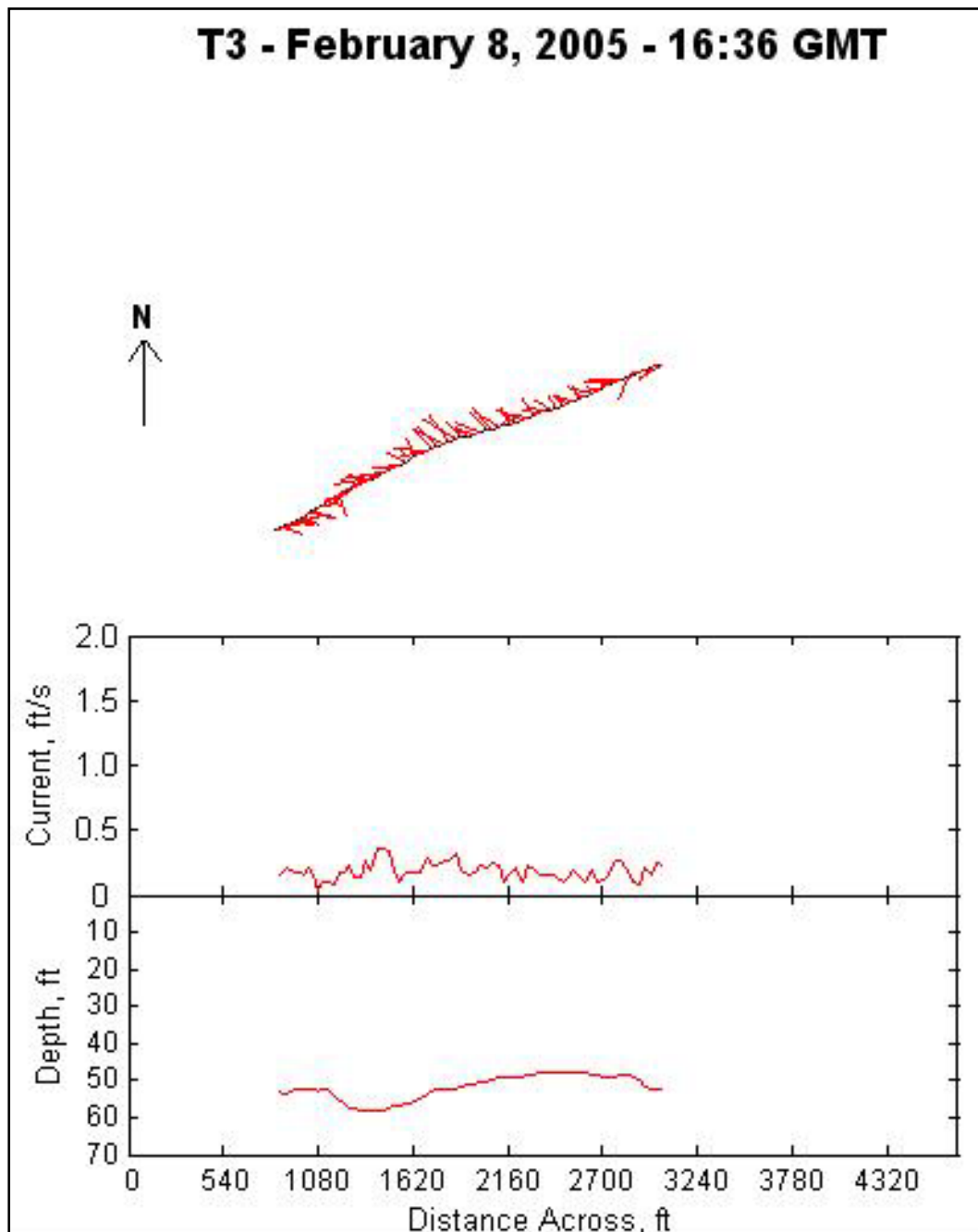


Figure D21. Transect 3 depth-averaged current plots, 8 February 2005, 1636 GMT.

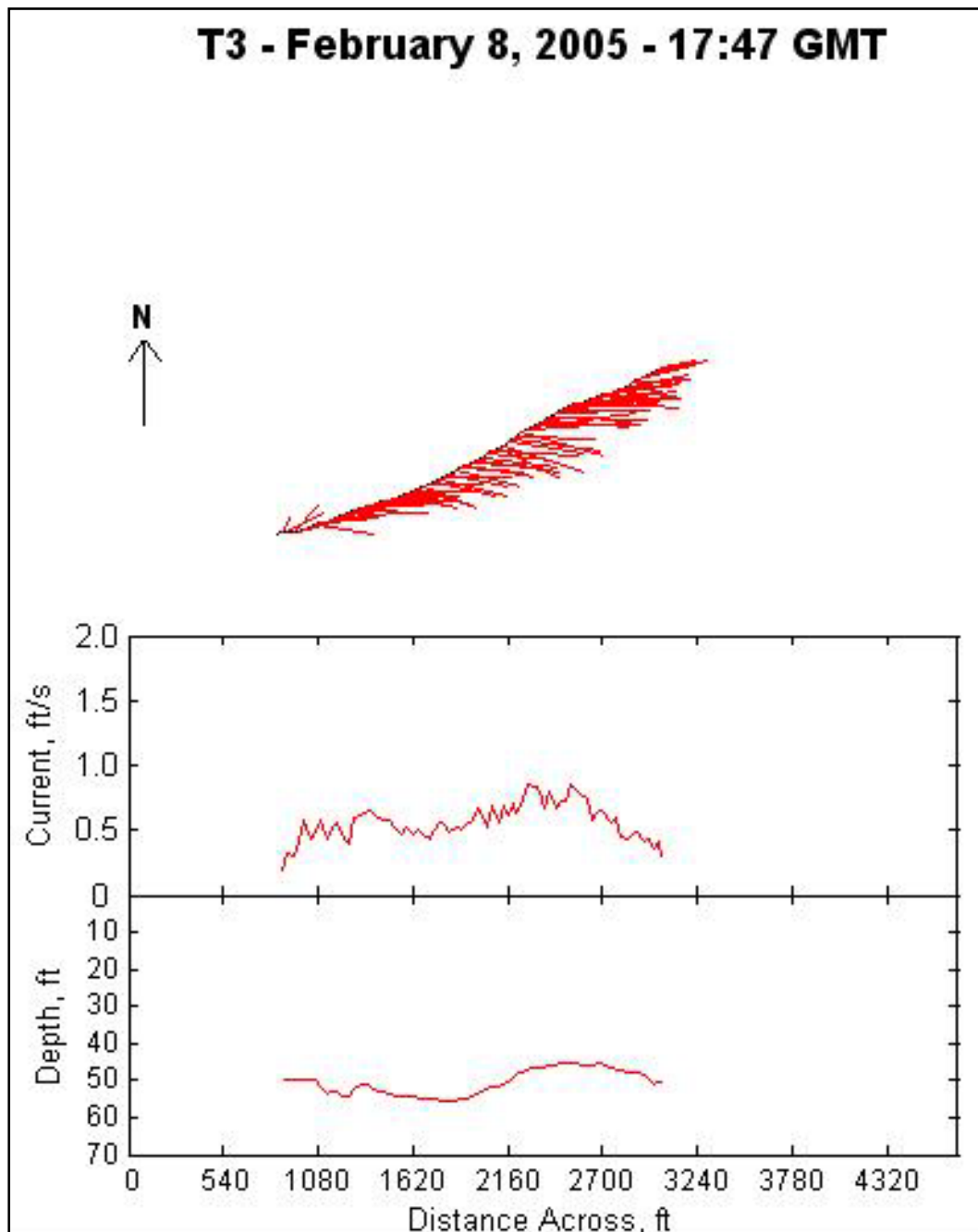


Figure D22. Transect 3 depth-averaged current plots, 8 February 2005, 1747 GMT.

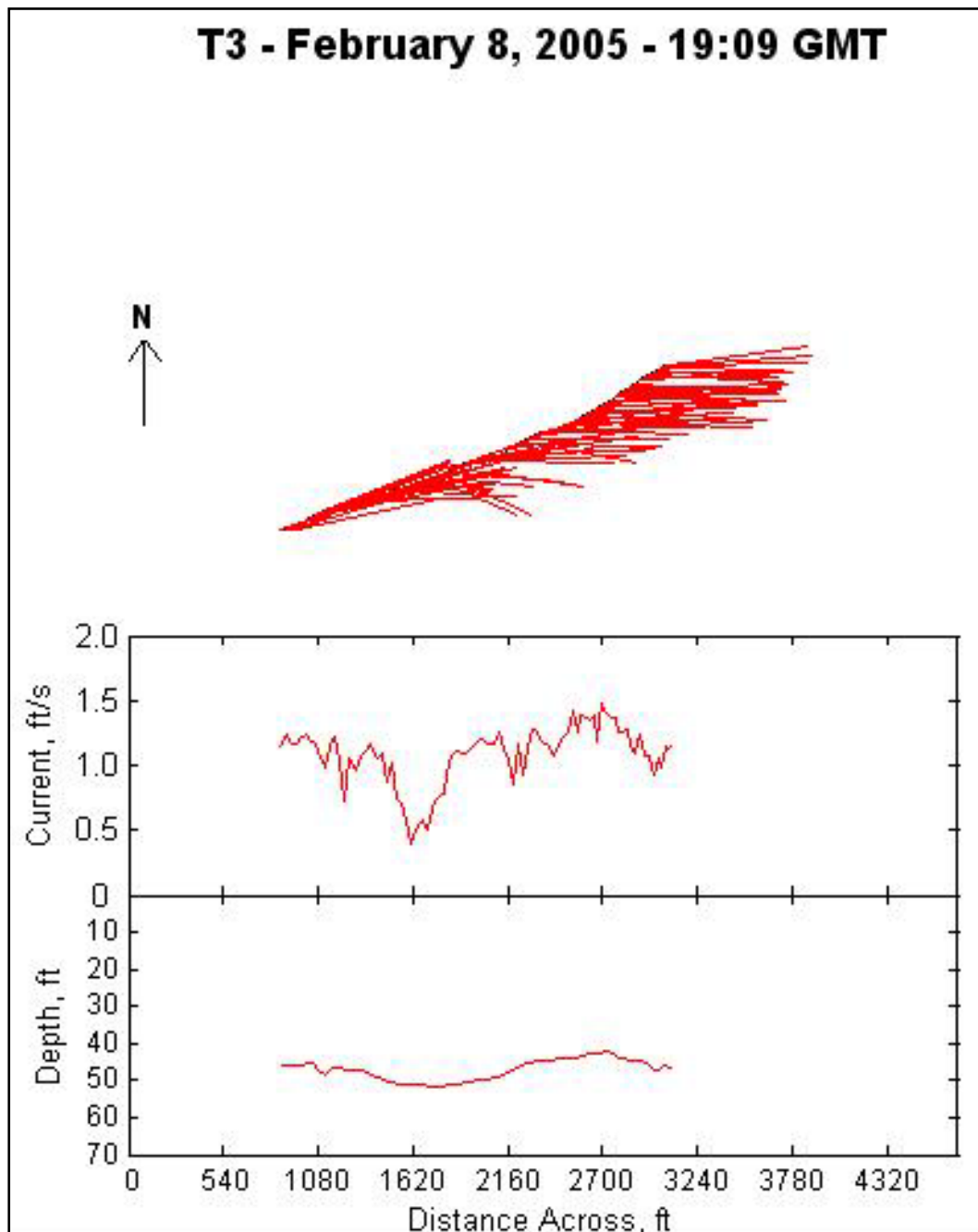


Figure D23. Transect 3 depth-averaged current plots, 8 February 2005, 1909 GMT.

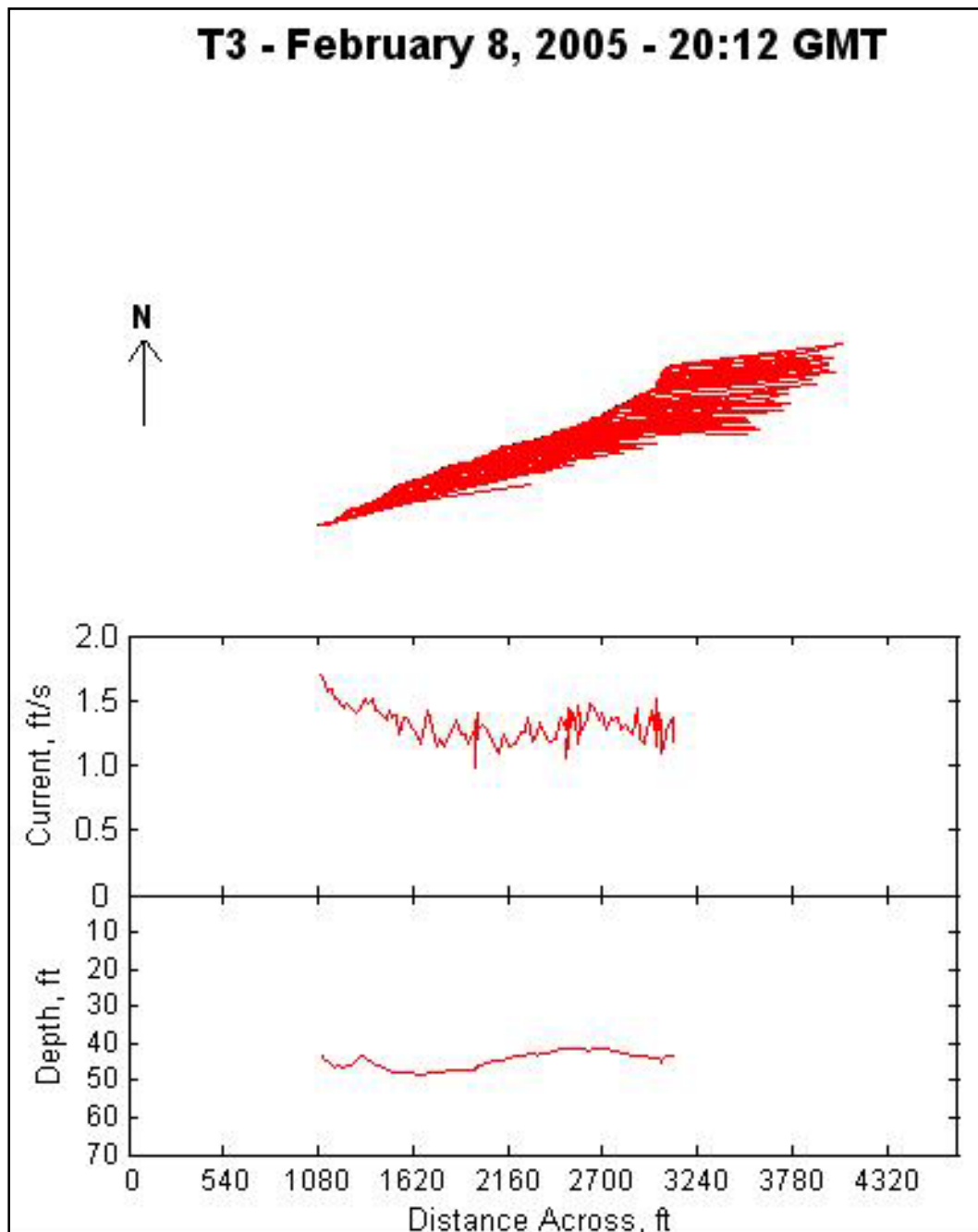


Figure D24. Transect 3 depth-averaged current plots, 8 February 2005, 2012 GMT.

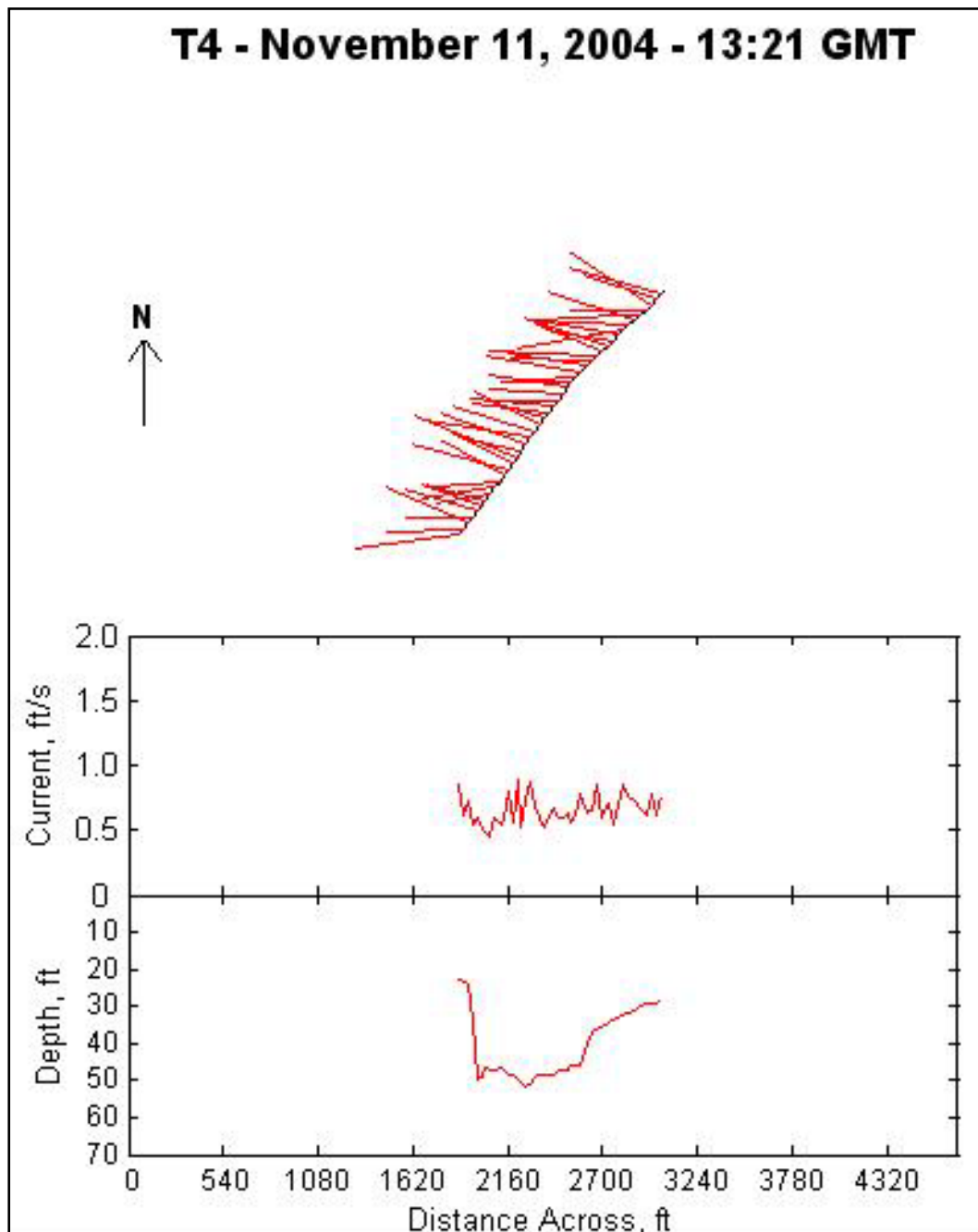


Figure D25. Transect 4 depth-averaged current plots, 11 November 2004, 1321 GMT.

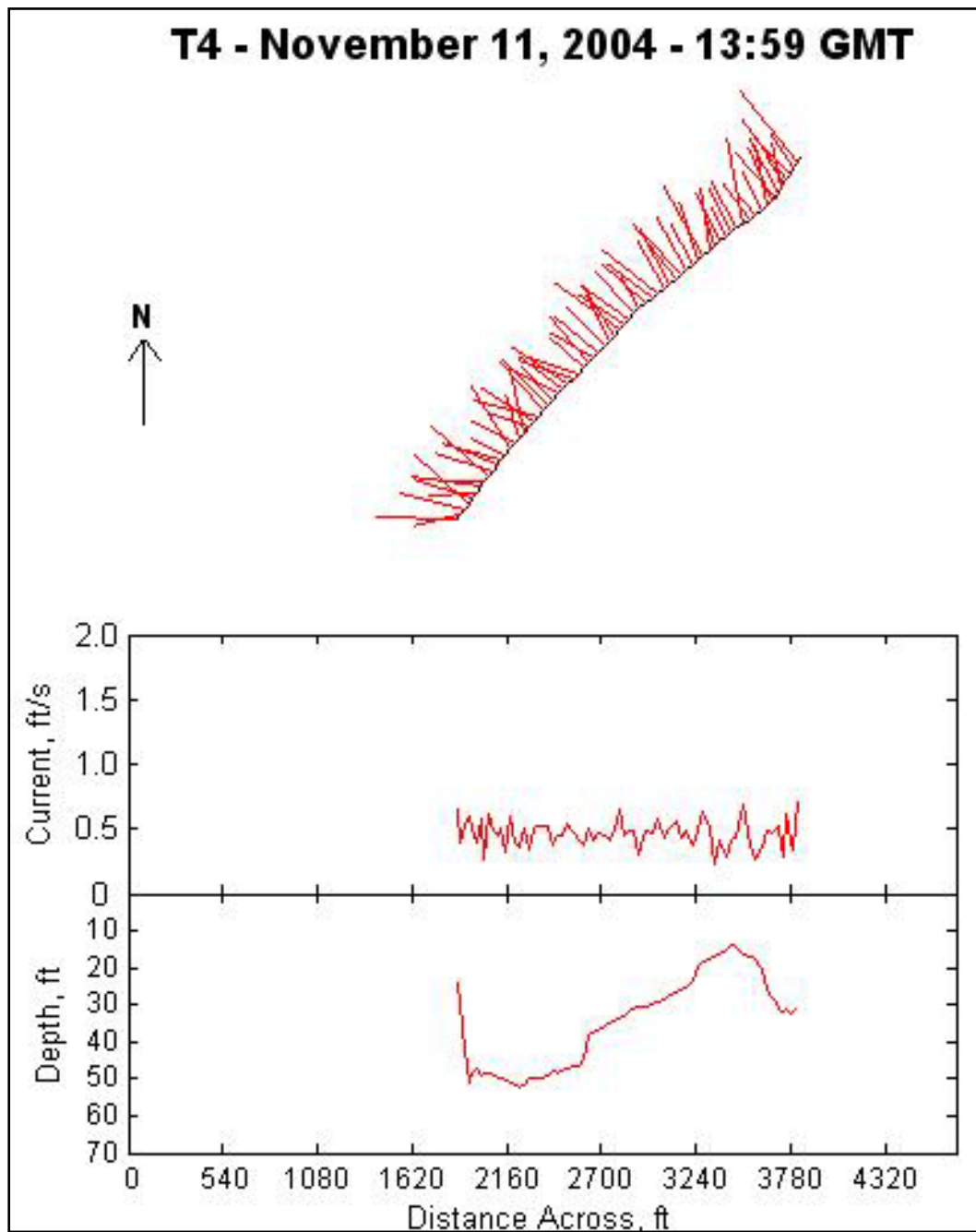


Figure D26. Transect 4 depth-averaged current plots, 11 November 2004, 1359 GMT.

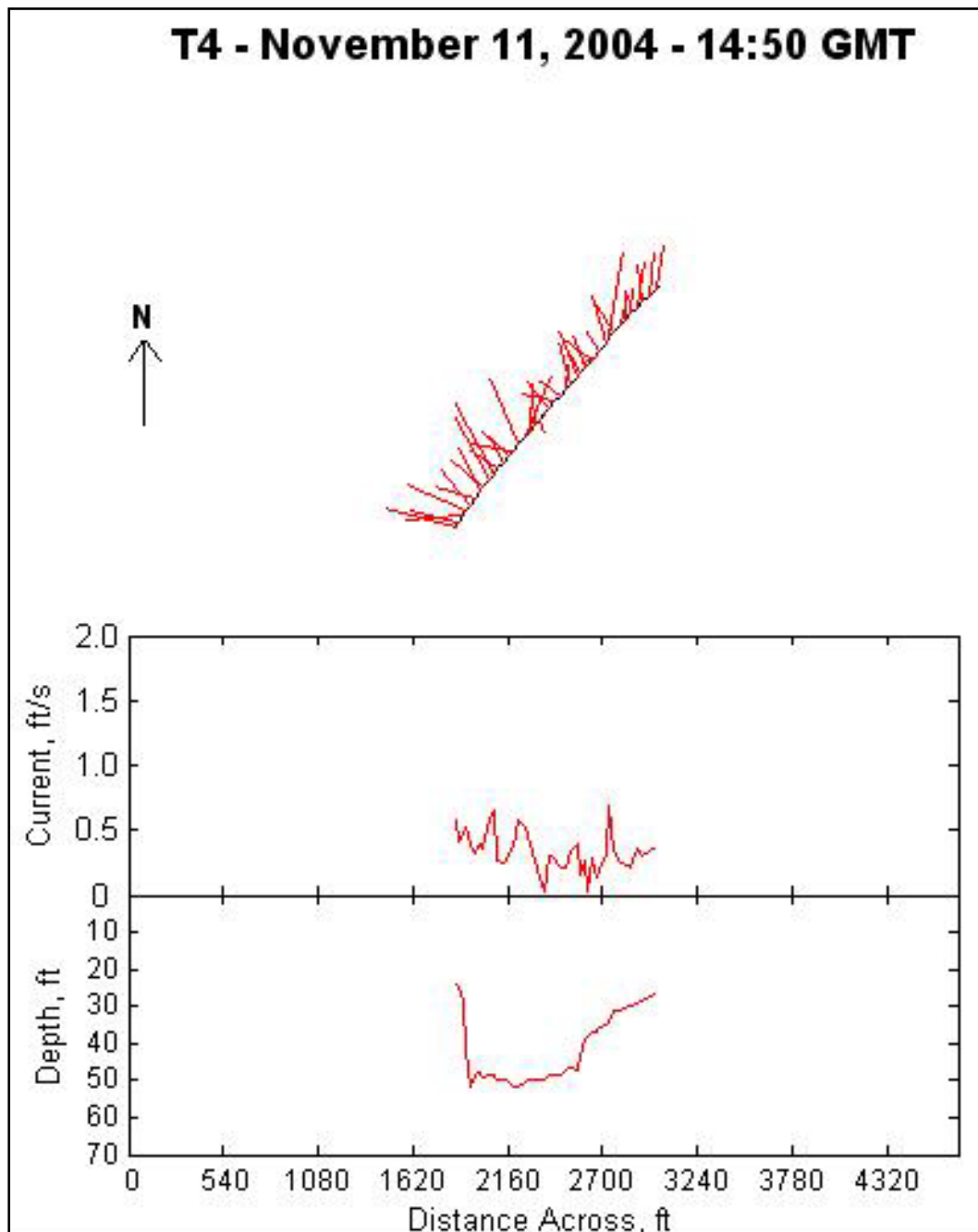


Figure D27. Transect 4 depth-averaged current plots, 11 November 2004, 1450 GMT.

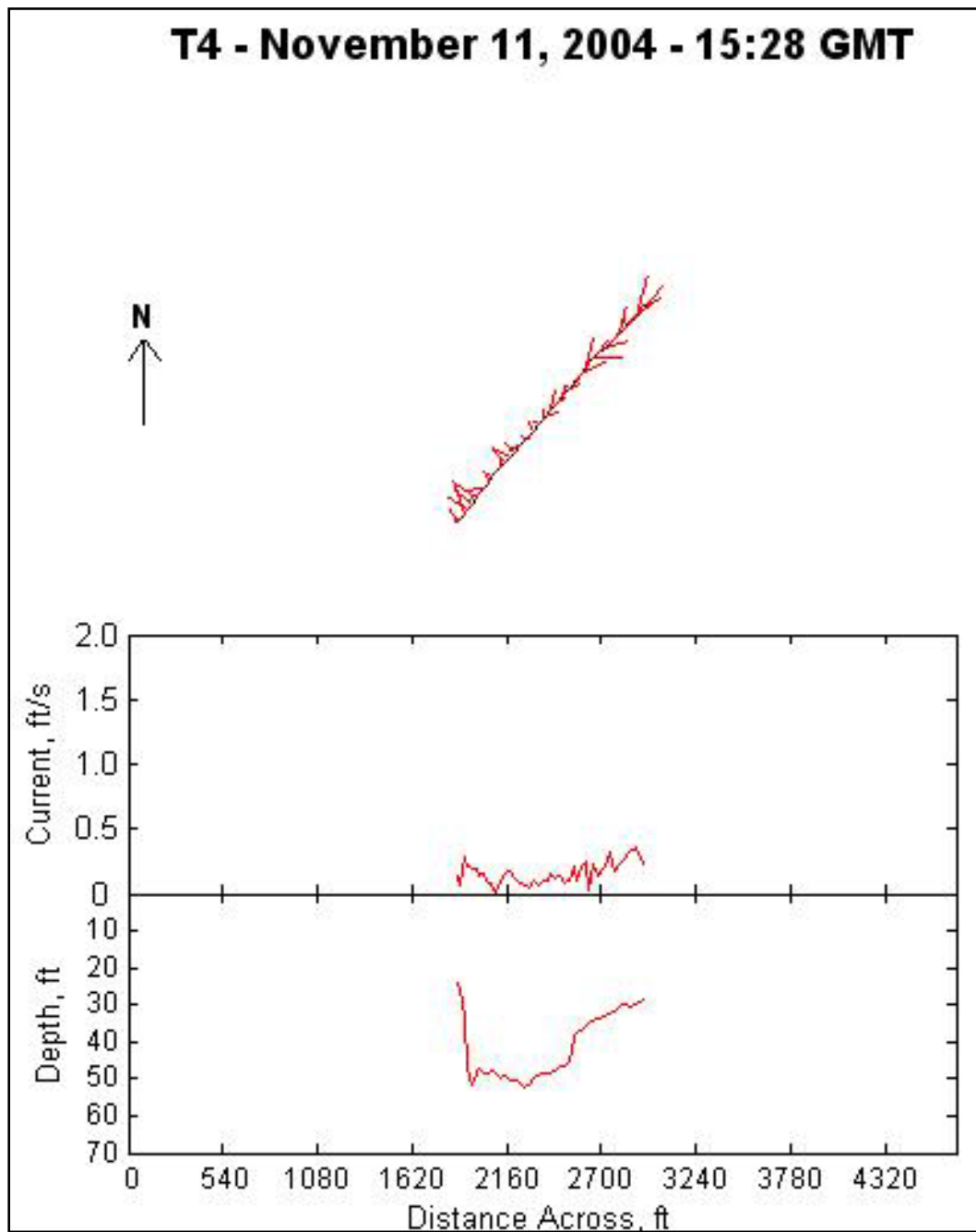


Figure D28. Transect 4 depth-averaged current plots, 11 November 2004, 1528 GMT.

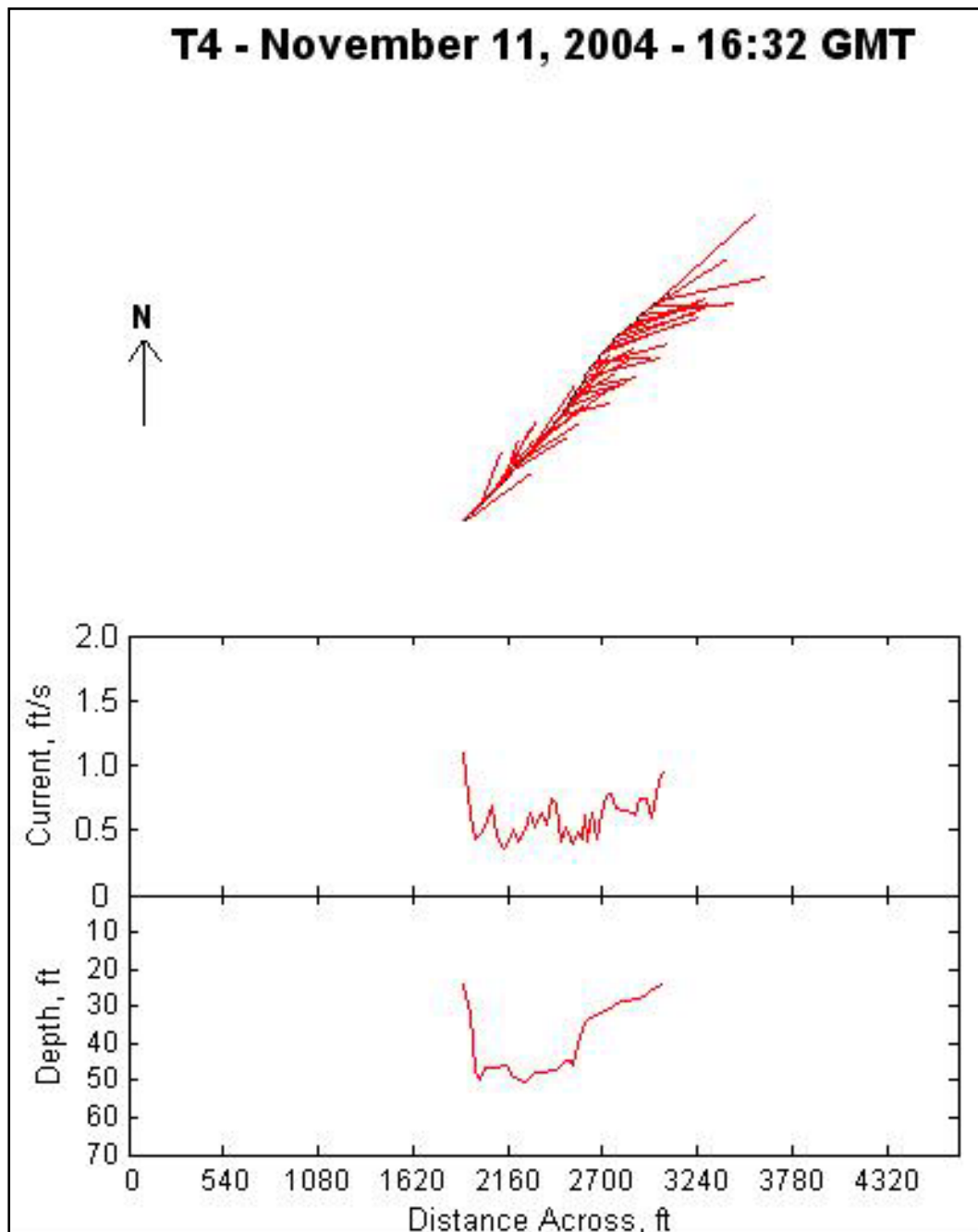


Figure D29. Transect 4 depth-averaged current plots, 11 November 2004, 1632 GMT.

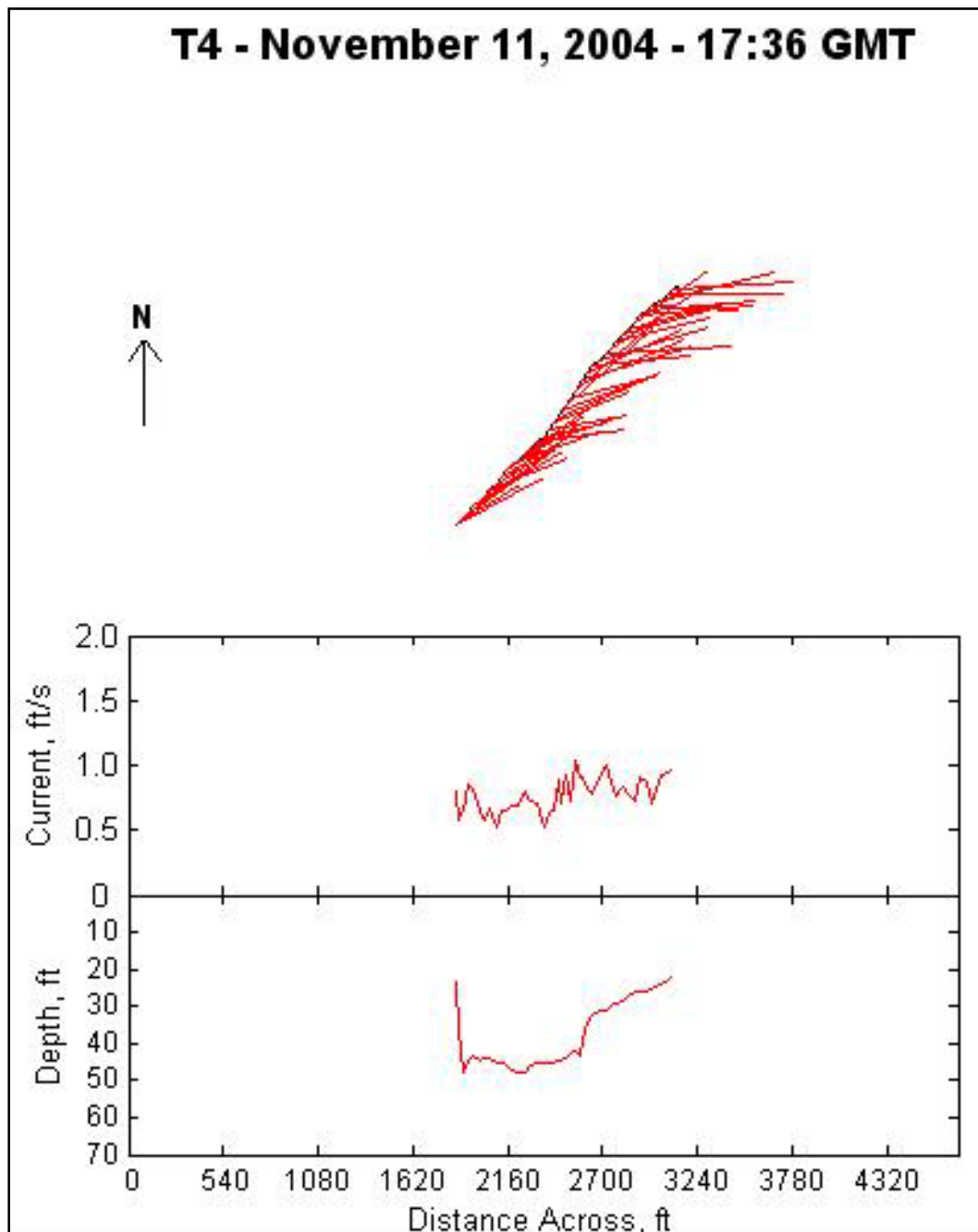


Figure D30. Transect 4 depth-averaged current plots, 11 November 2004, 1736 GMT.

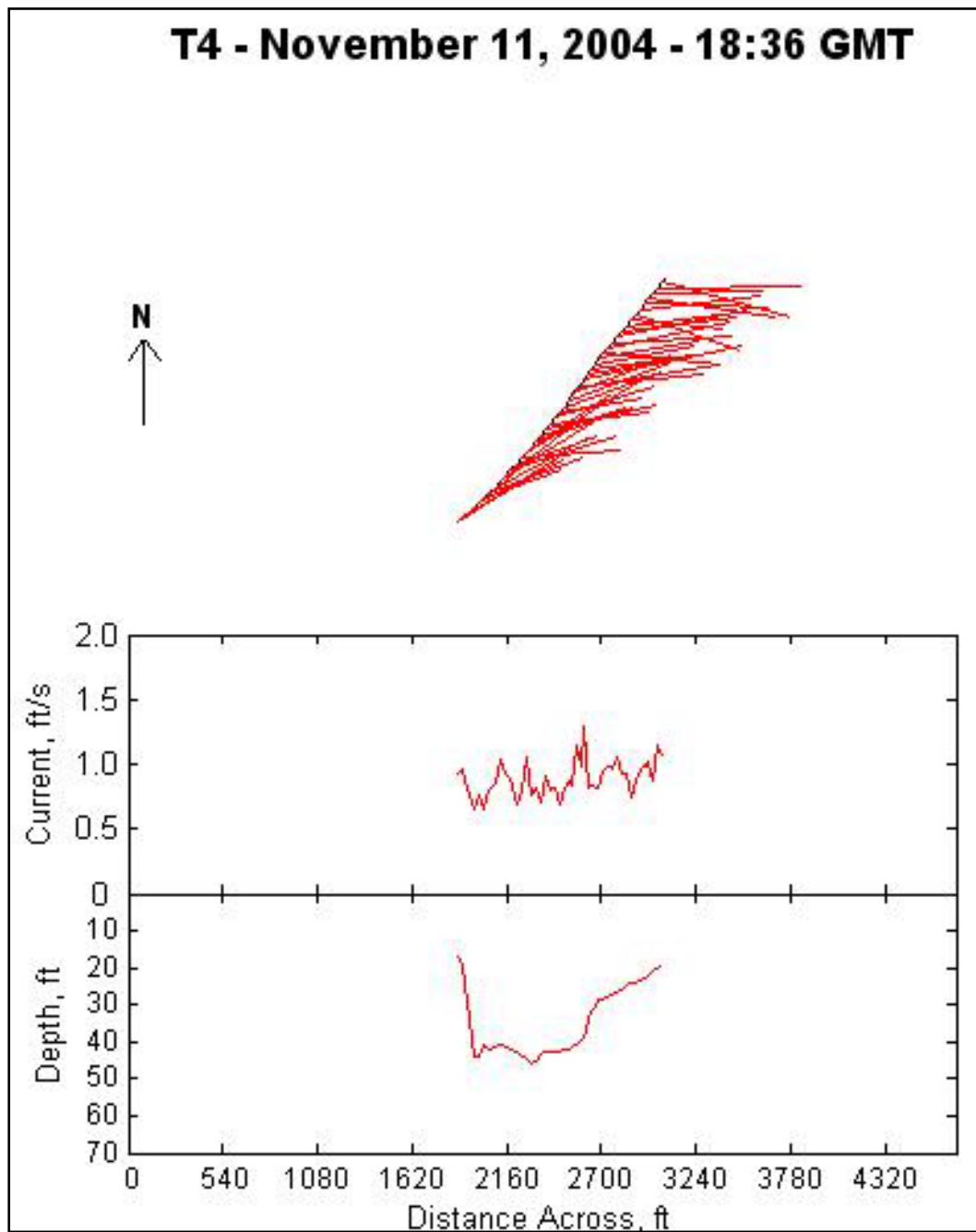


Figure D31. Transect 4 depth-averaged current plots, 11 November 2004, 1836 GMT.

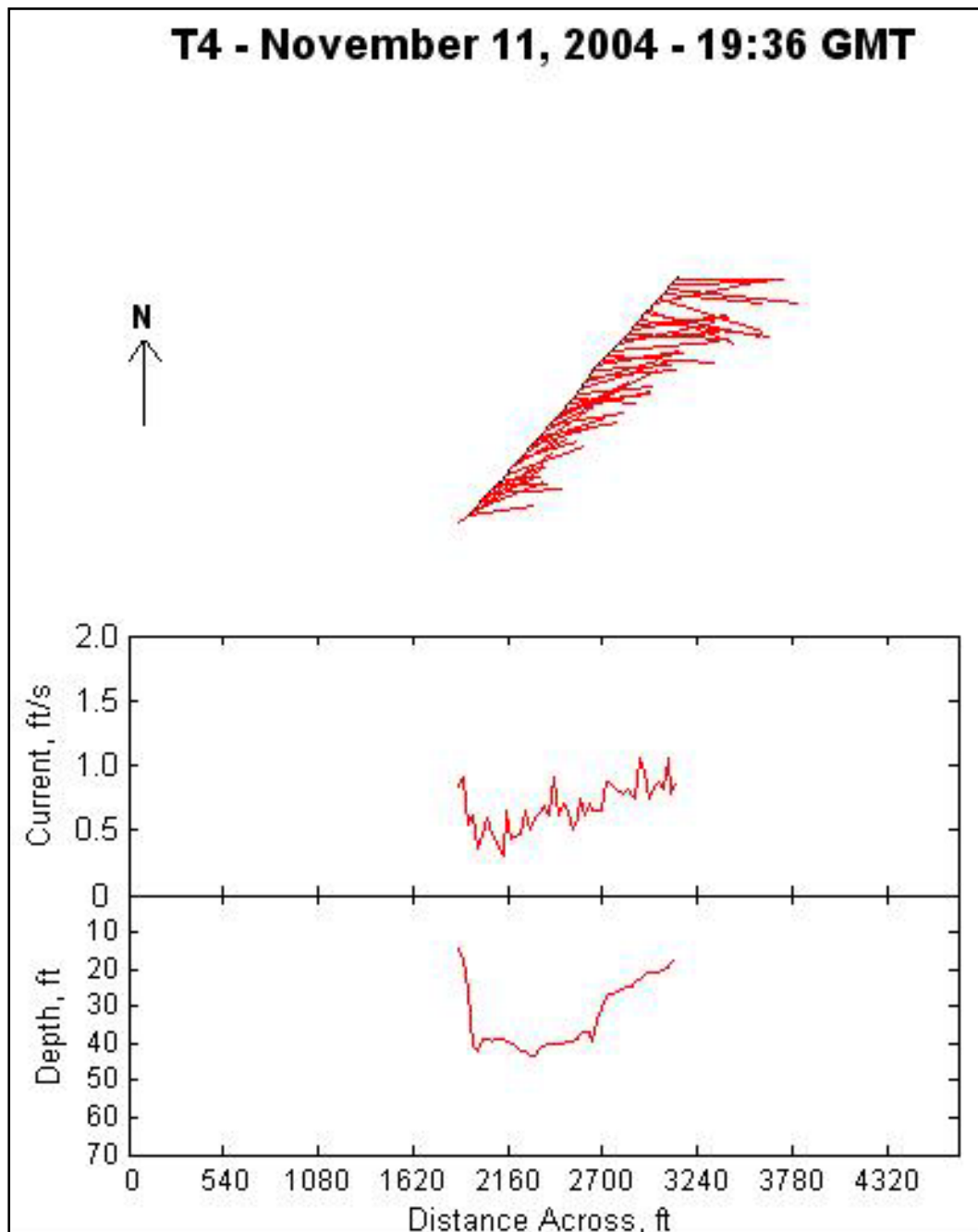


Figure D32. Transect 4 depth-averaged current plots, 11 November 2004, 1936 GMT.

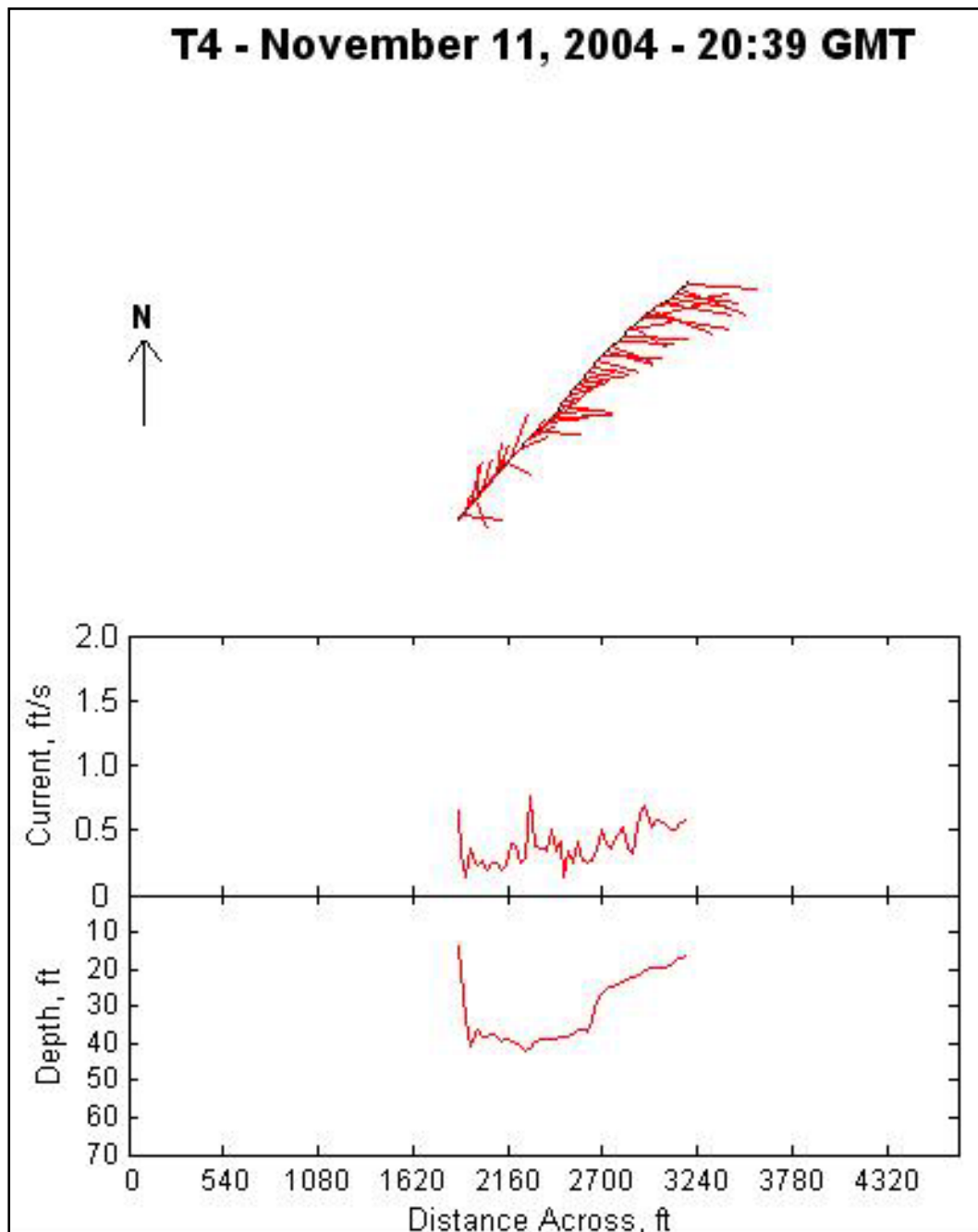


Figure D33. Transect 4 depth-averaged current plots, 11 November 2004, 2039 GMT.

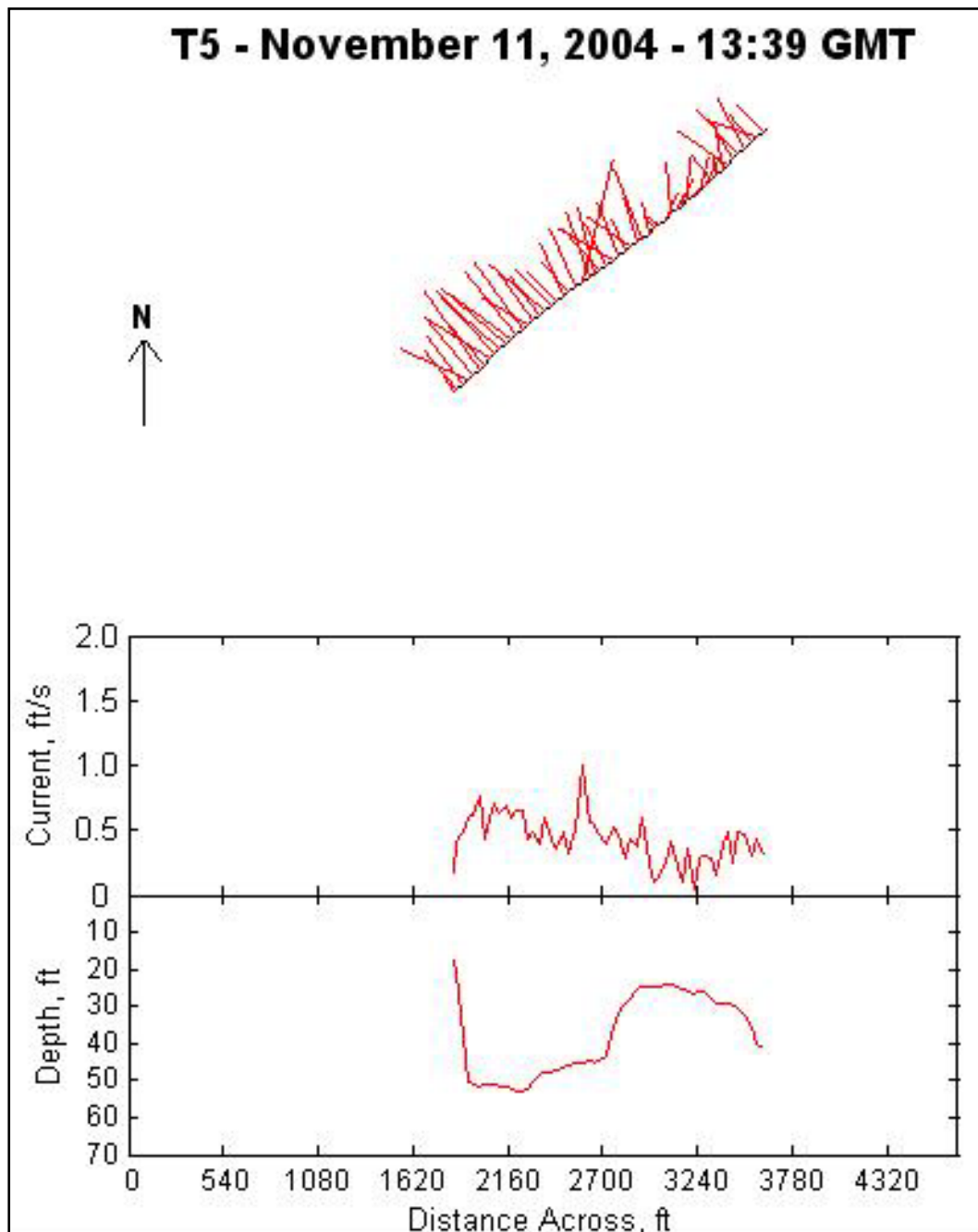


Figure D34. Transect 5 depth-averaged current plots, 11 November 2004, 1339 GMT.

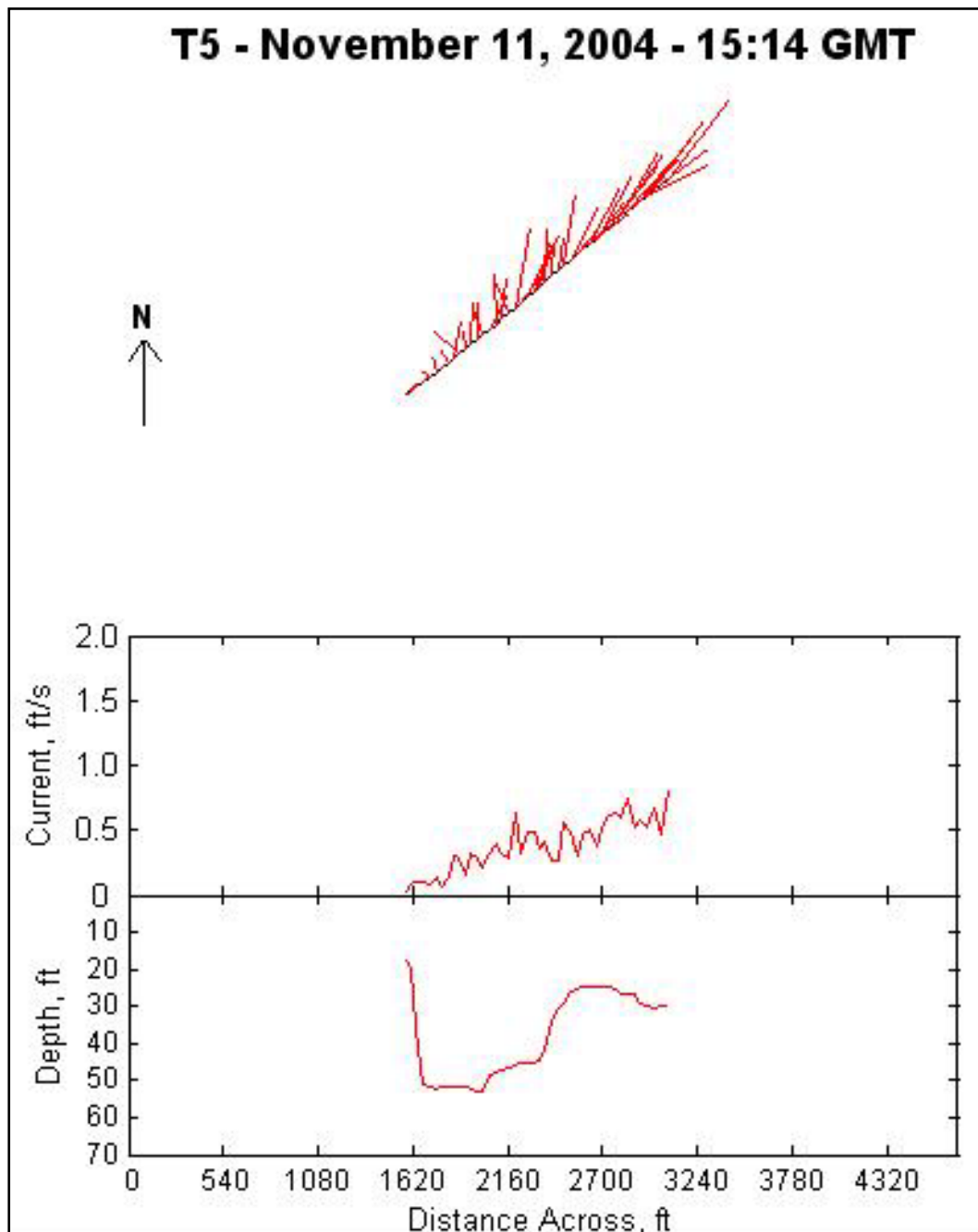


Figure D35. Transect 5 depth-averaged current plots, 11 November 2004, 1514 GMT.

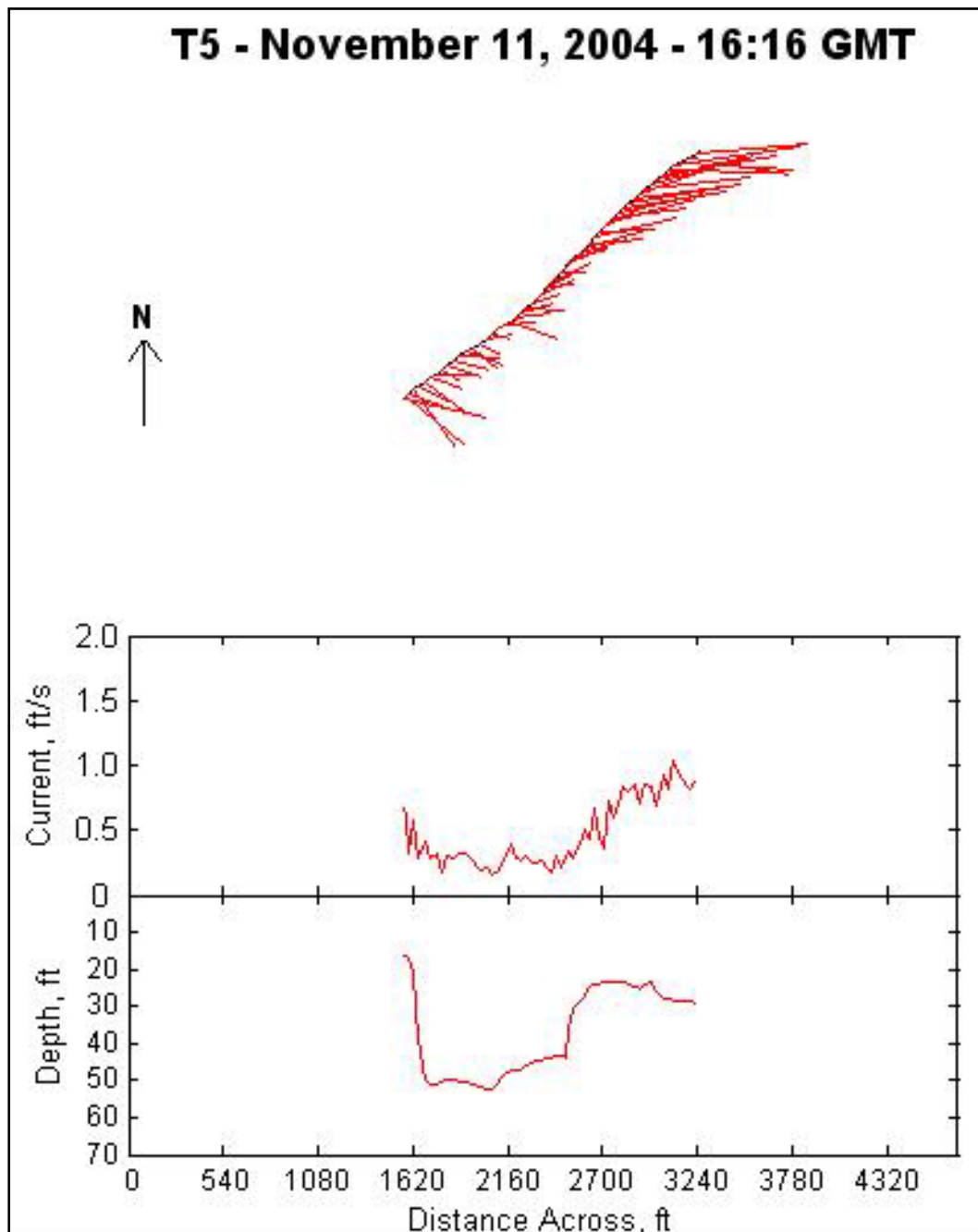


Figure D36. Transect 5 depth-averaged current plots, 11 November 2004, 1616 GMT.

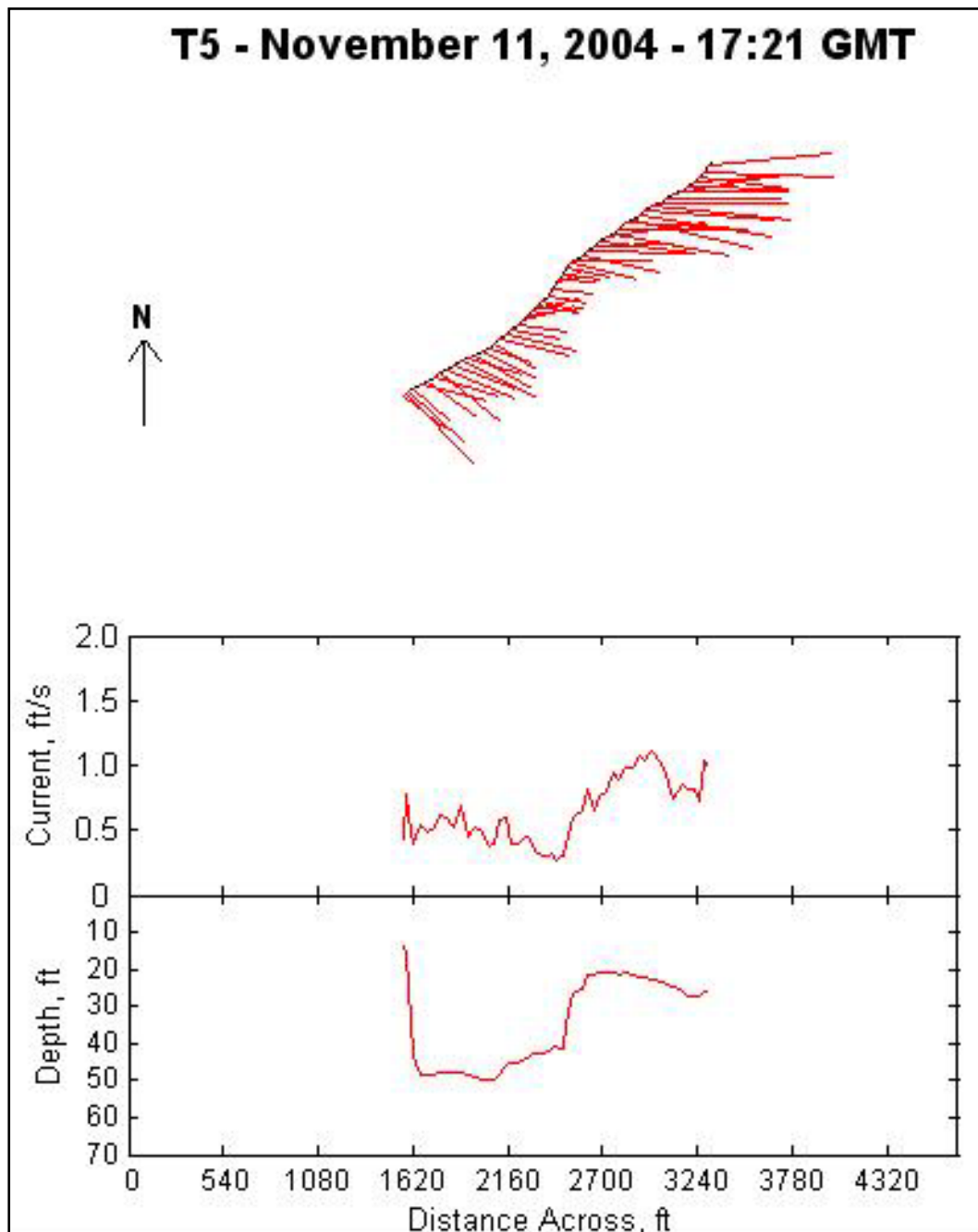


Figure D37. Transect 5 depth-averaged current plots, 11 November 2004, 1721 GMT.

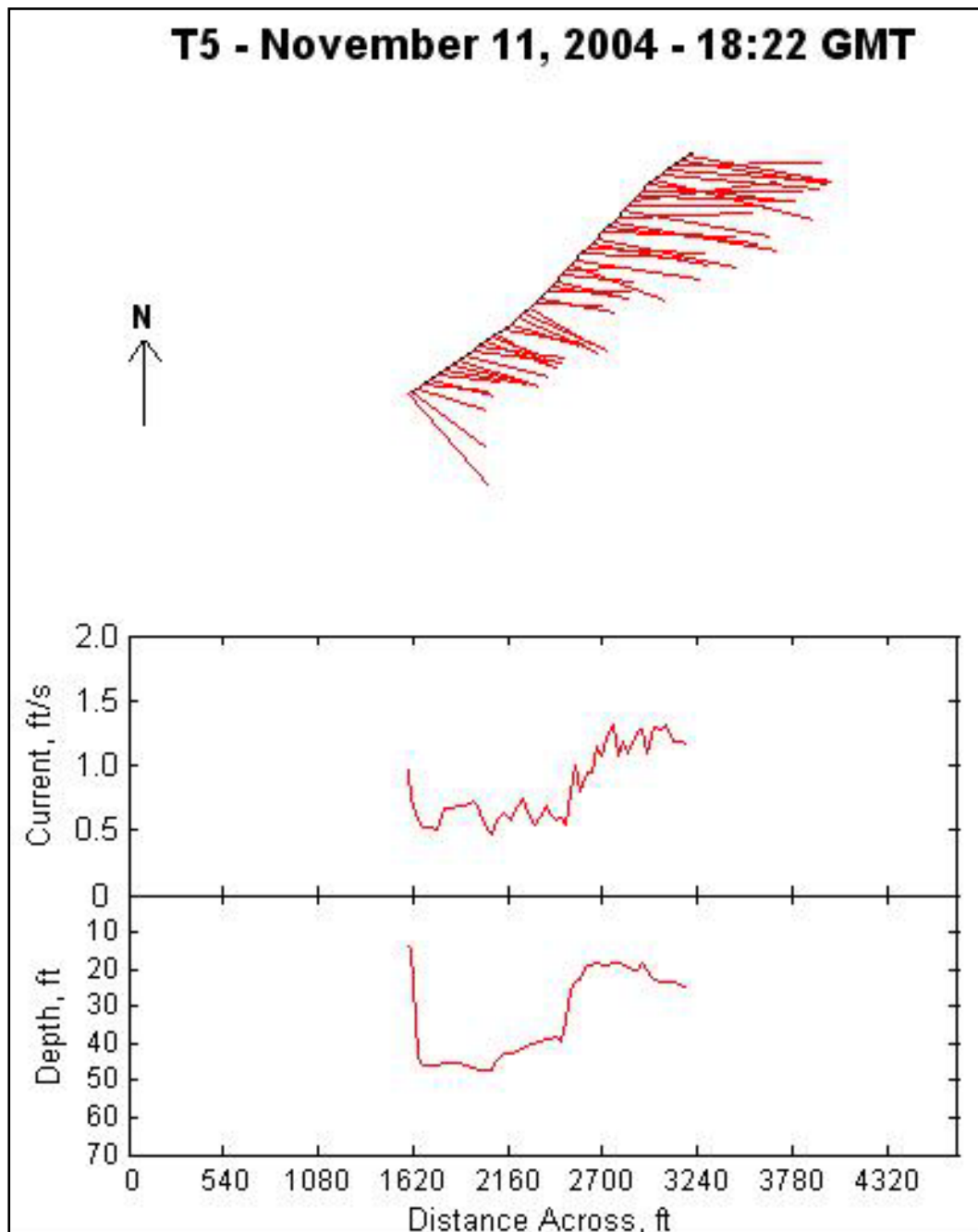


Figure D38. Transect 5 depth-averaged current plots, 11 November 2004, 1822 GMT.

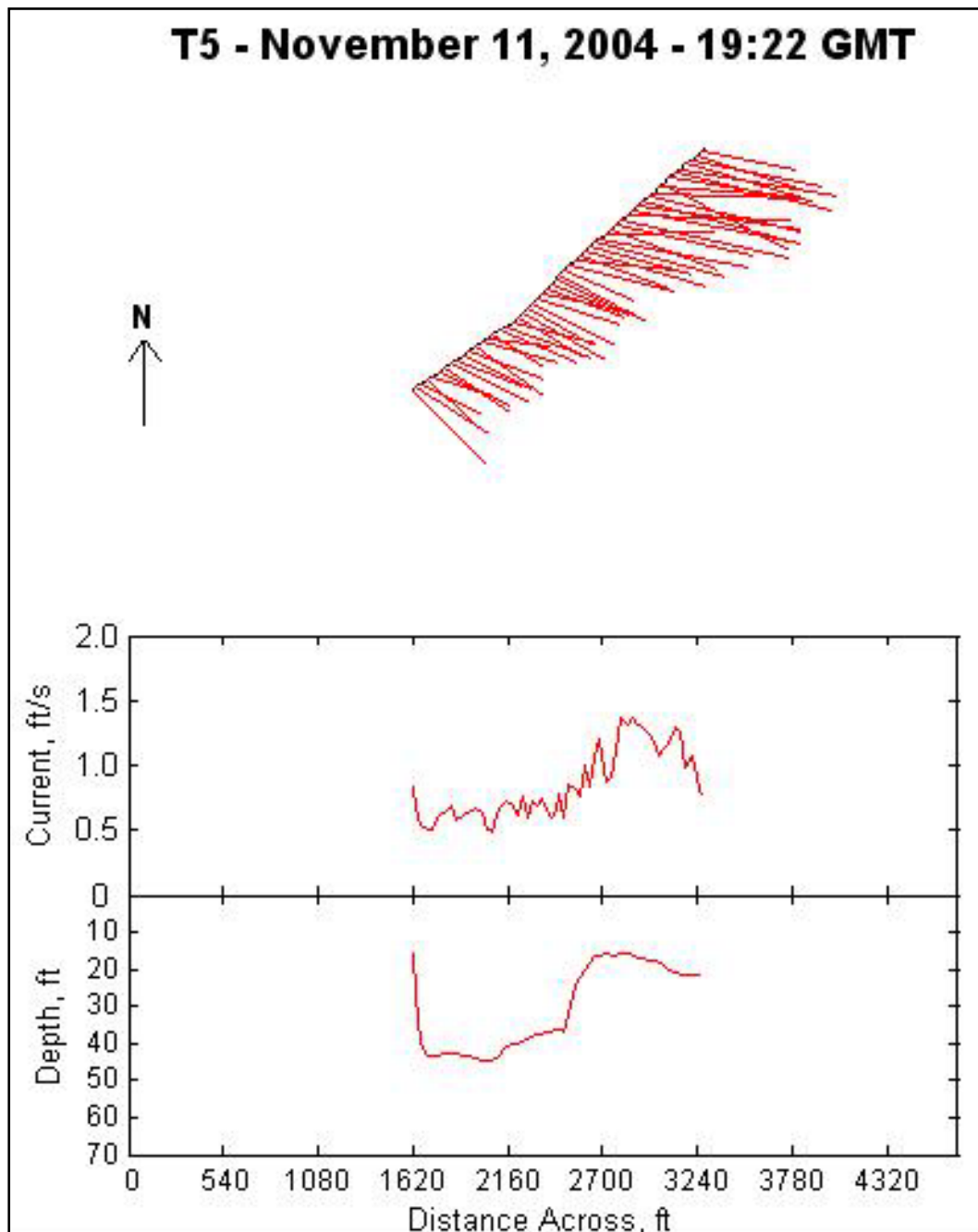


Figure D39. Transect 5 depth-averaged current plots, 11 November 2004, 1922 GMT.

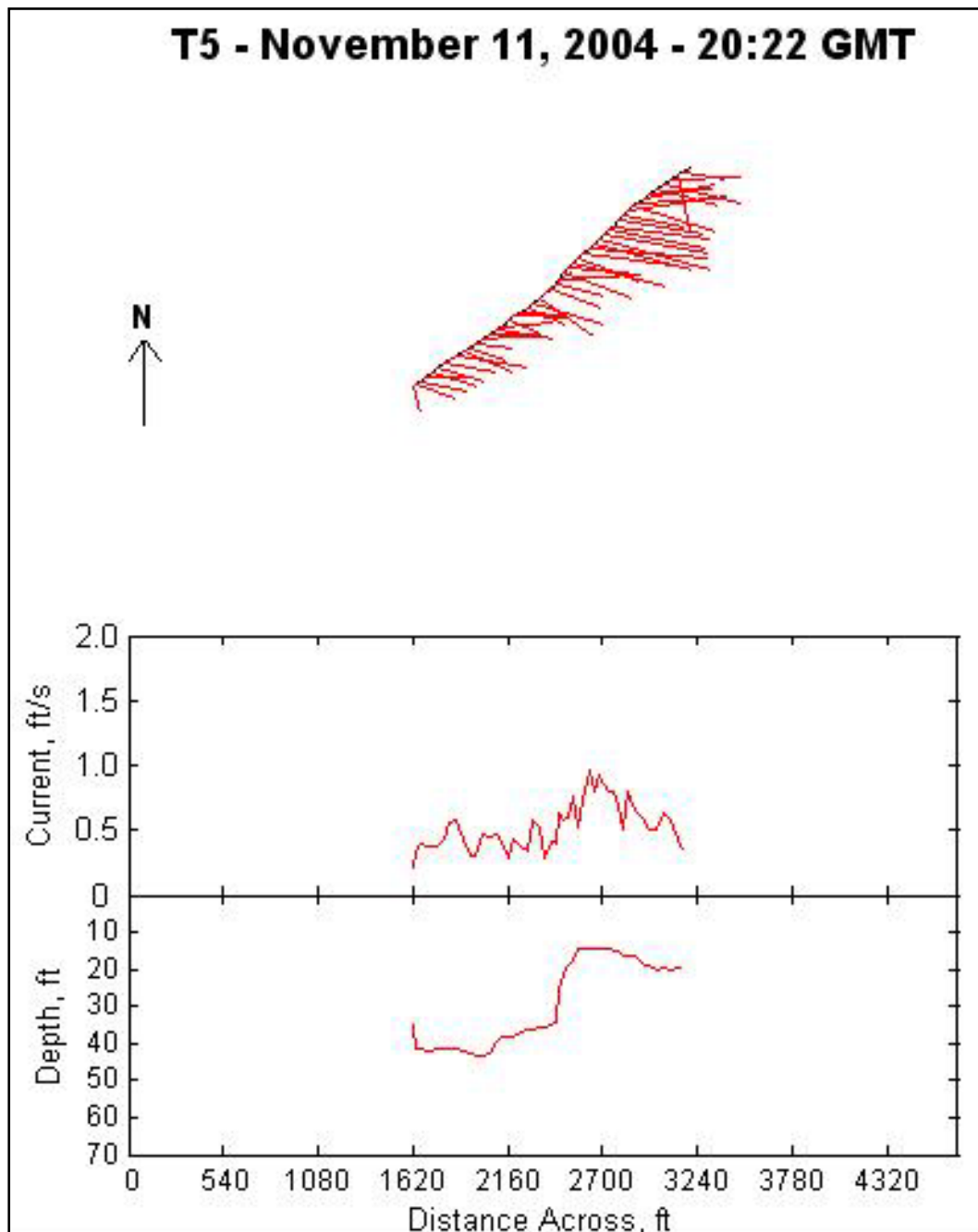


Figure D40. Transect 5 depth-averaged current plots, 11 November 2004, 20:22 GMT.

## Appendix E: Transect Current Surveys, Current Velocity Cross Sections

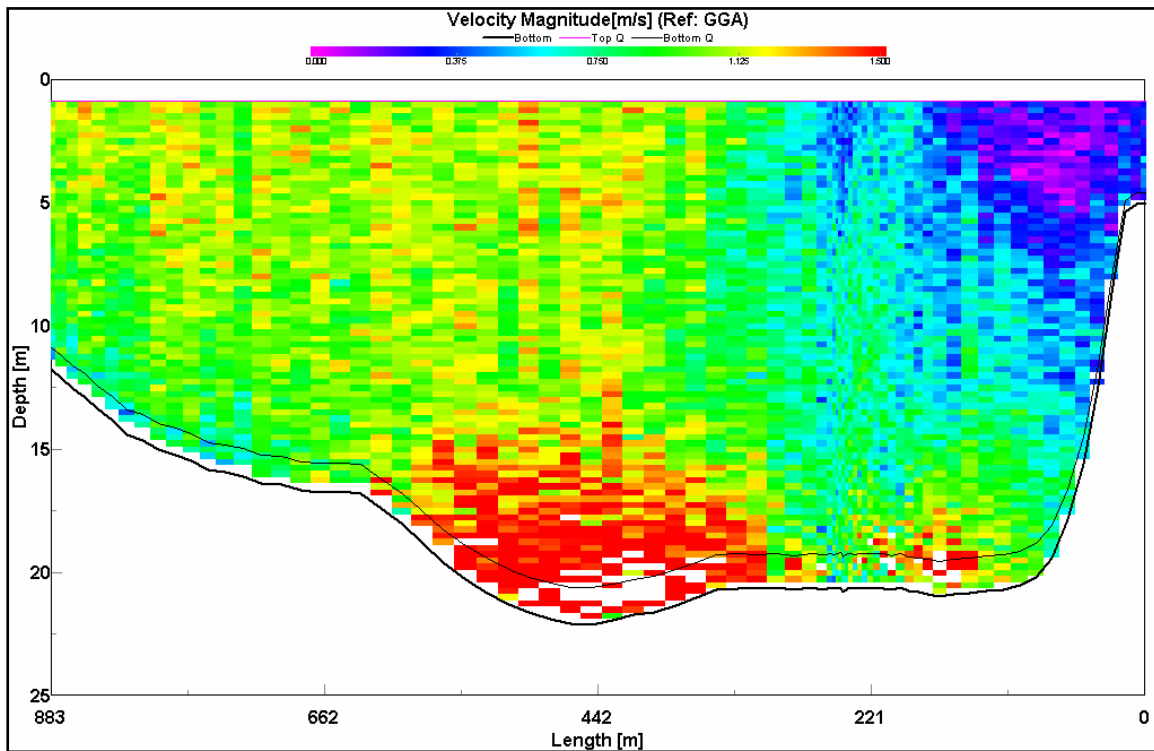


Figure E1. Transect 1 current velocity cross sections, 8 February 2005, 1341 GMT.

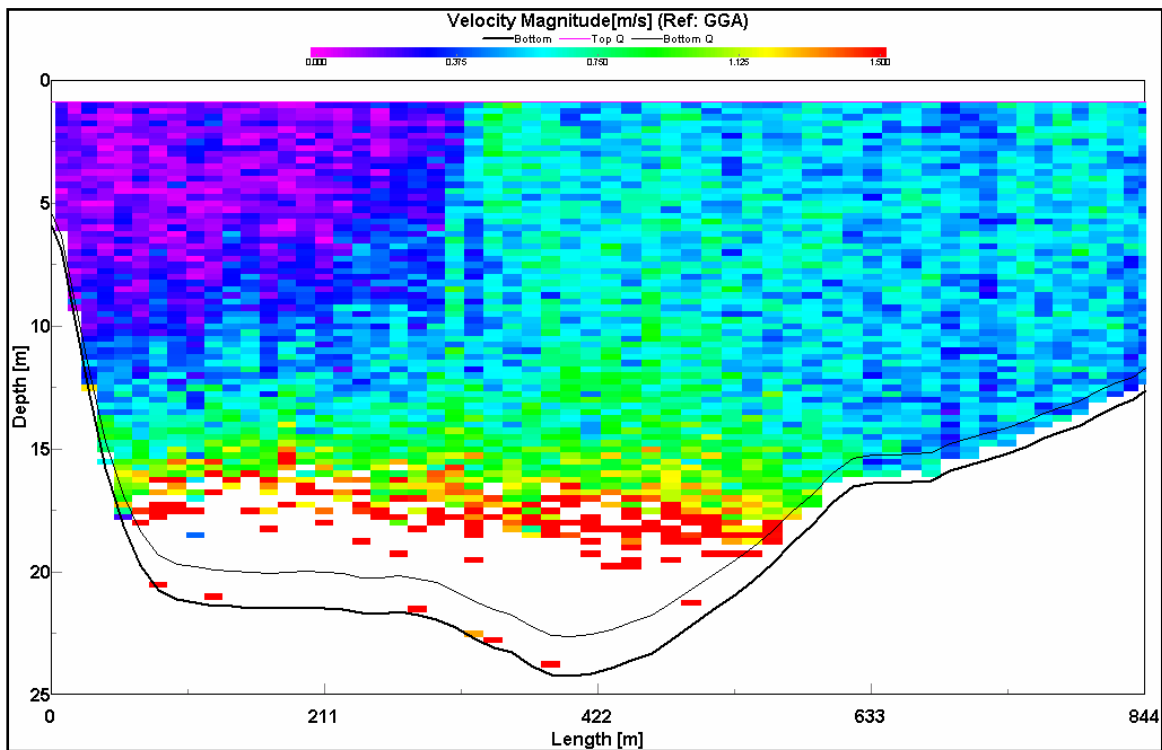


Figure E2. Transect 1 current velocity cross sections, 8 February 2005, 1450 GMT.

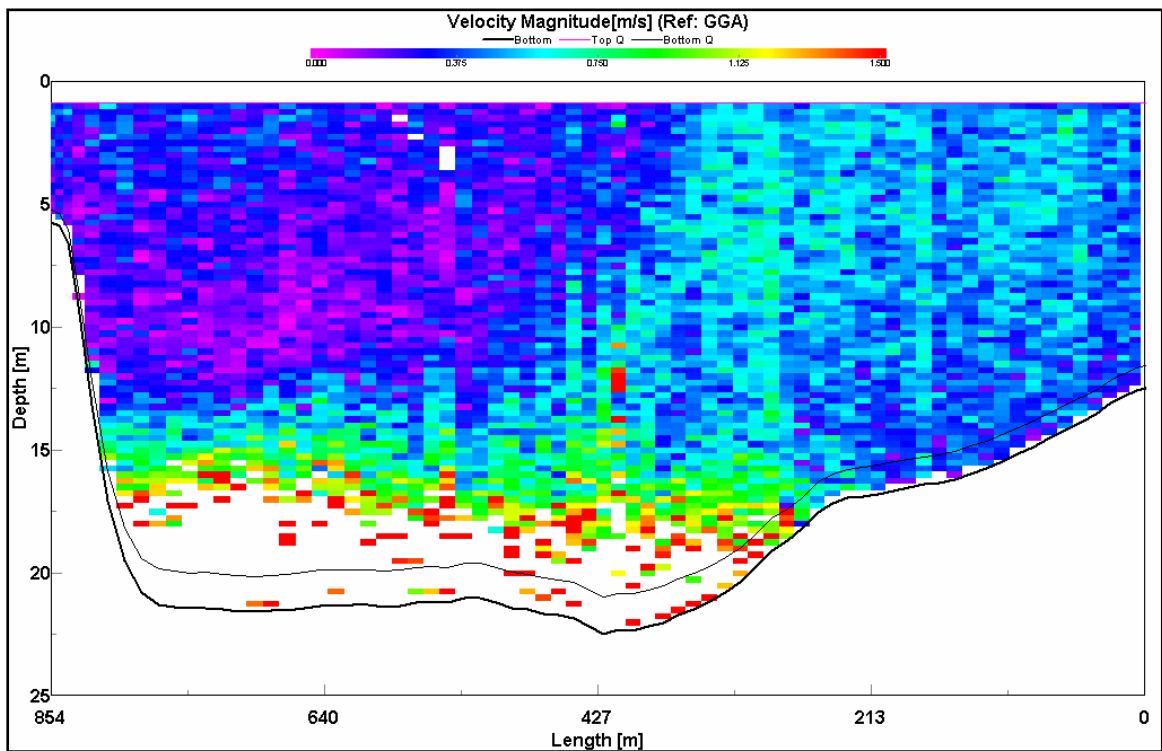


Figure E3. Transect 1 current velocity cross sections, 8 February 2005, 1459 GMT.

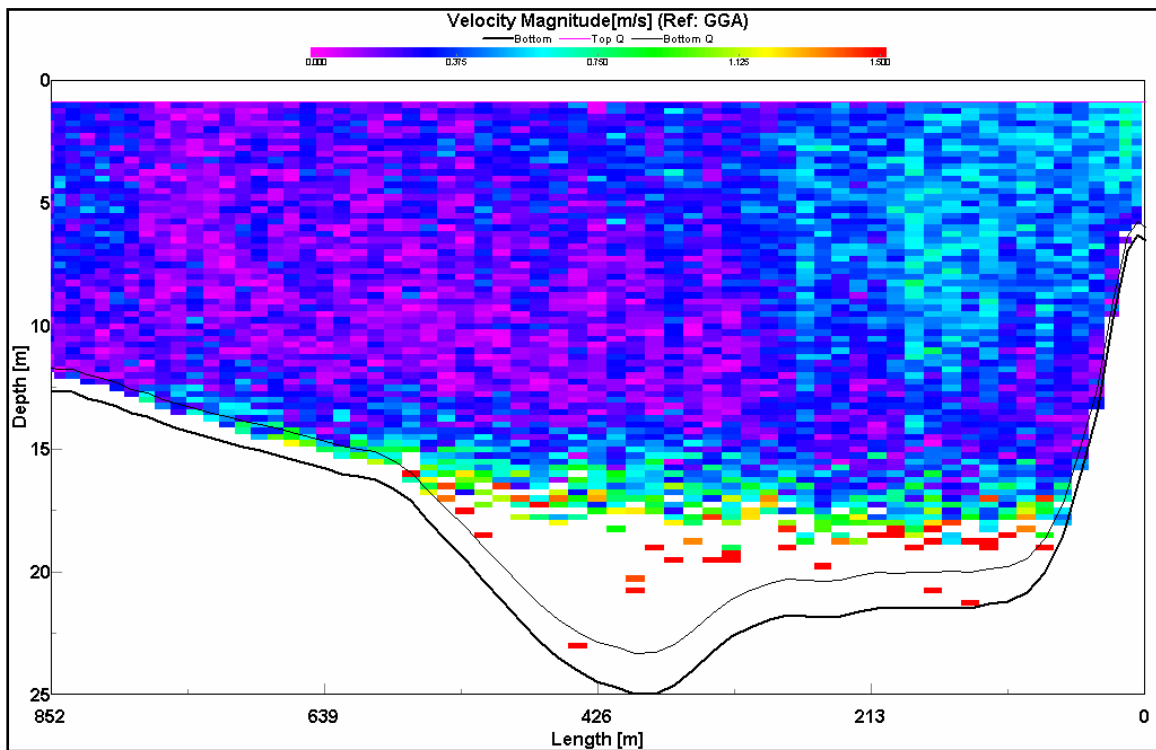


Figure E4. Transect 1 current velocity cross sections, 8 February 2005, 1604 GMT.

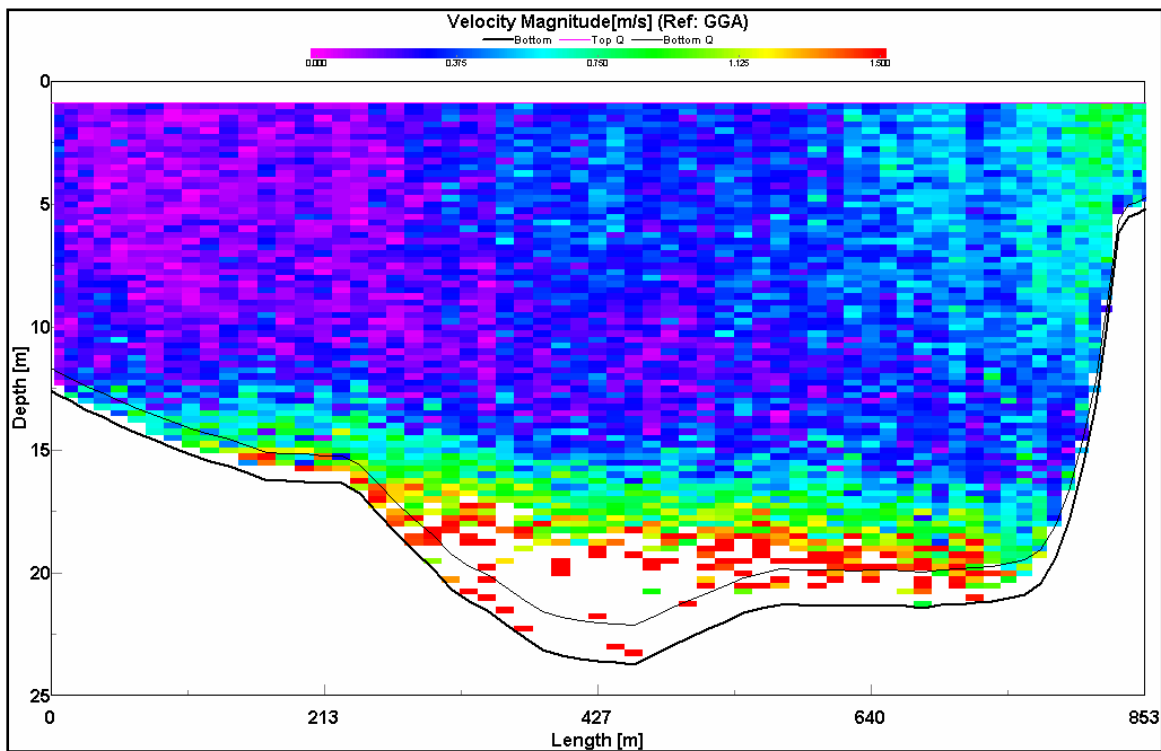


Figure E5. Transect 1 current velocity cross sections, 8 February 2005, 1614 GMT.

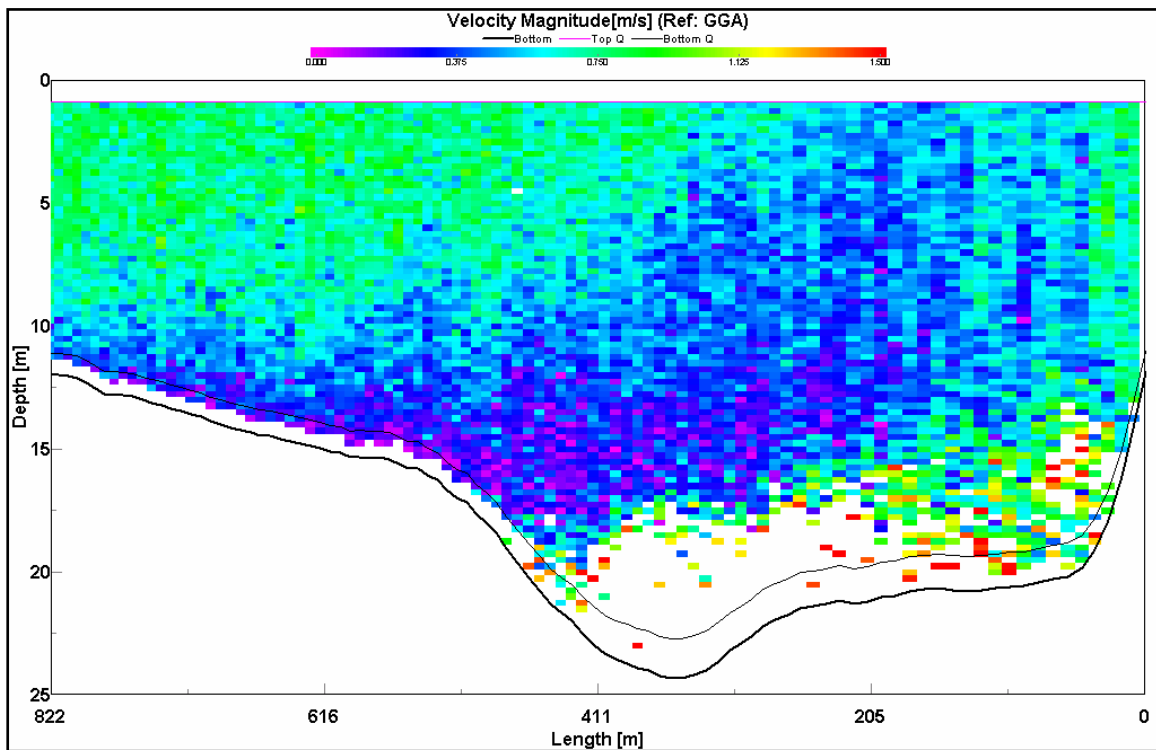


Figure E6. Transect 1 current velocity cross sections, 8 February 2005, 1723 GMT.

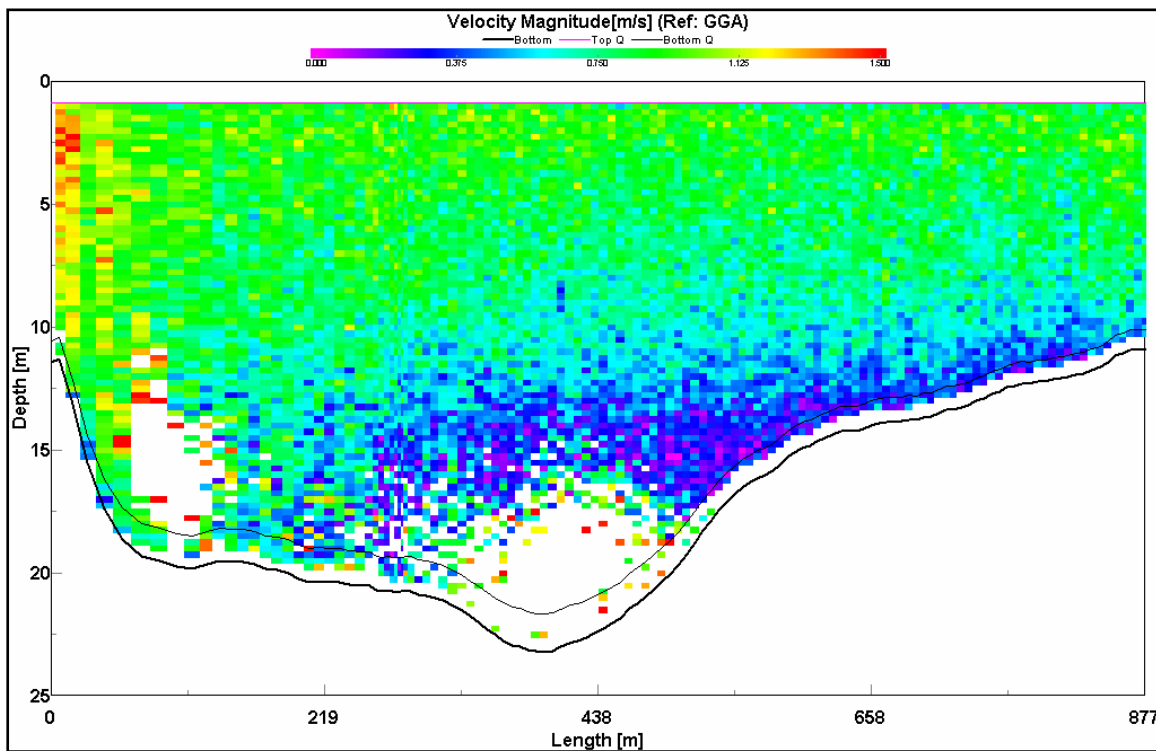


Figure E7. Transect 1 current velocity cross sections, 8 February 2005, 1840 GMT.

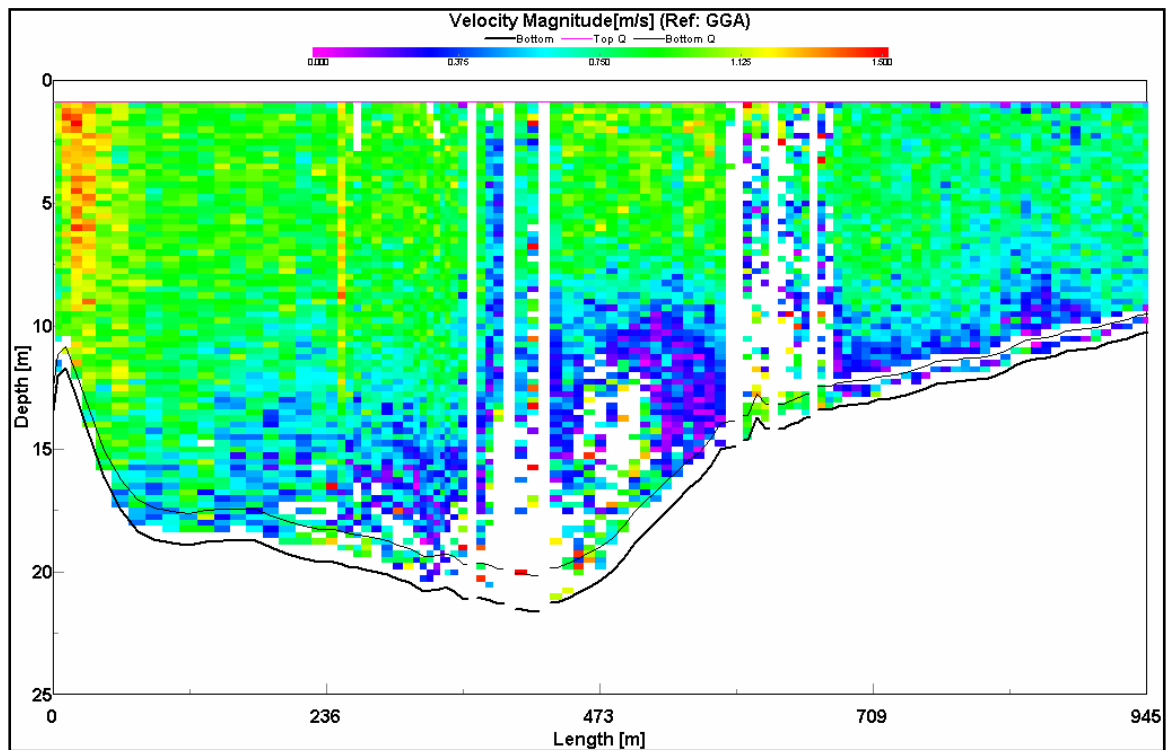


Figure E8. Transect 1 current velocity cross sections, 8 February 2005, 2048 GMT.

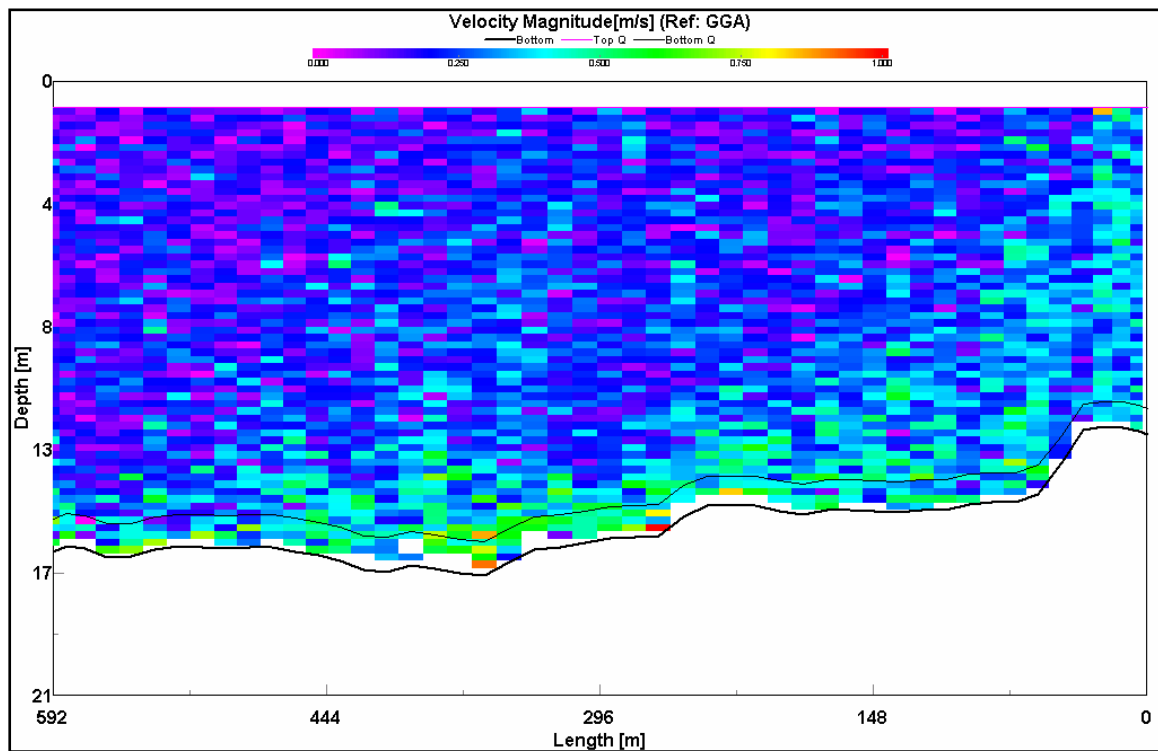


Figure E9. Transect 2 current velocity cross sections, 8 February 2005, 1415 GMT.

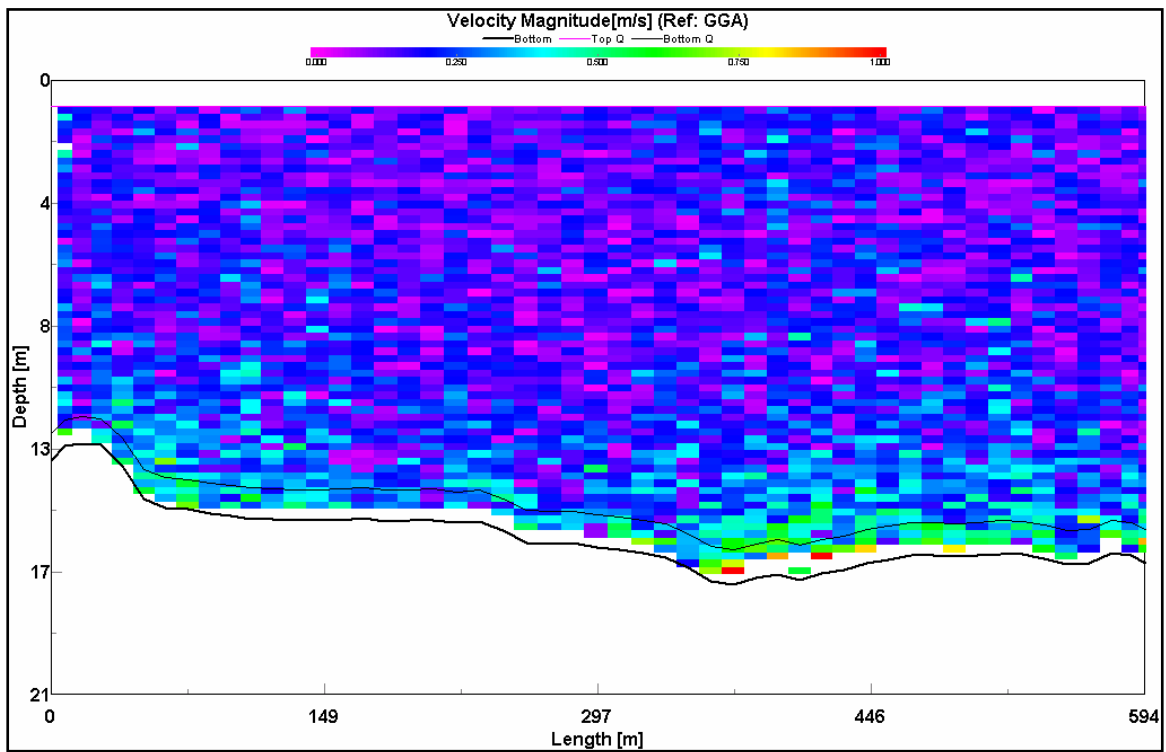


Figure E10. Transect 2 current velocity cross sections, 8 February 2005, 1532 GMT.

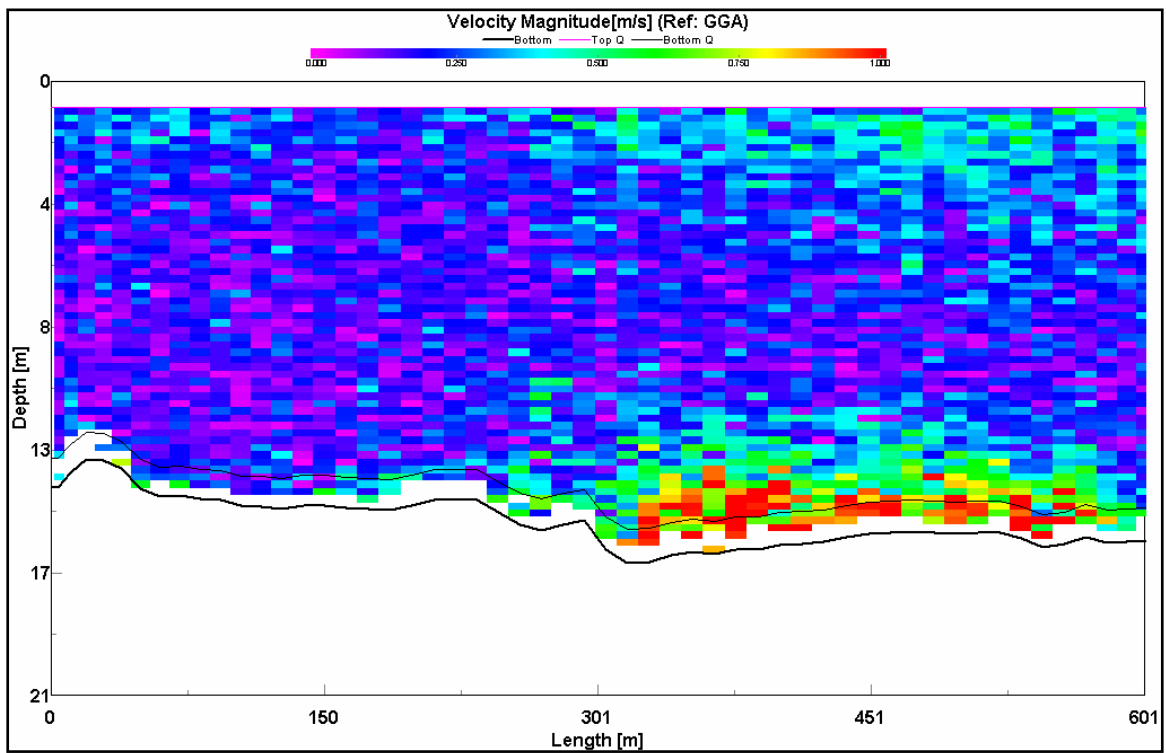


Figure E11. Transect 2 current velocity cross sections, 8 February 2005, 1649 GMT.

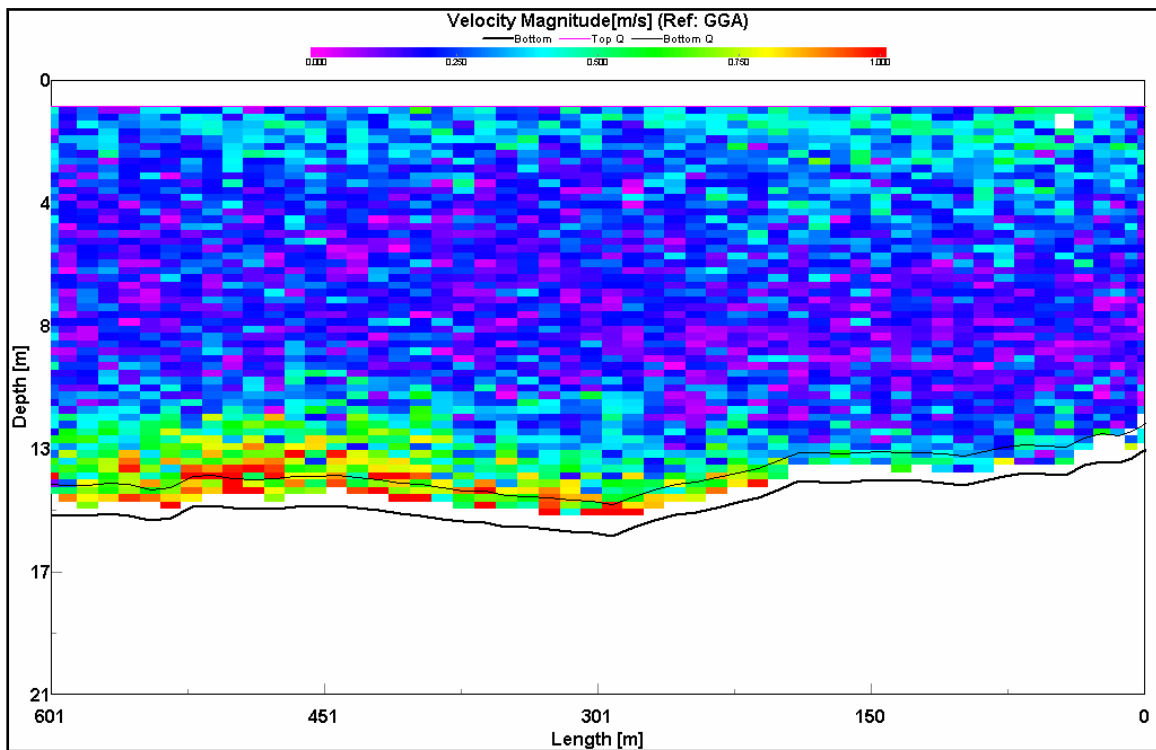


Figure E12. Transect 2 current velocity cross sections, 8 February 2005, 1803 GMT.

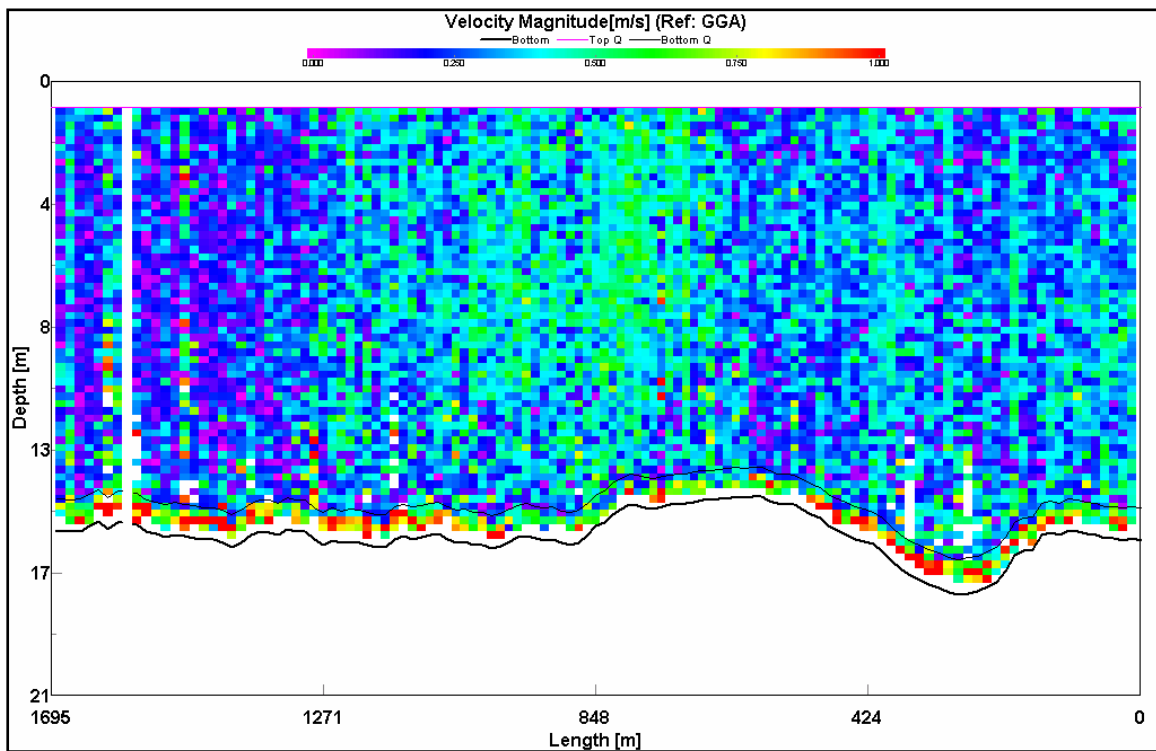


Figure E13. Transect 3 current velocity cross sections, 11 November 2004, 1424 GMT.

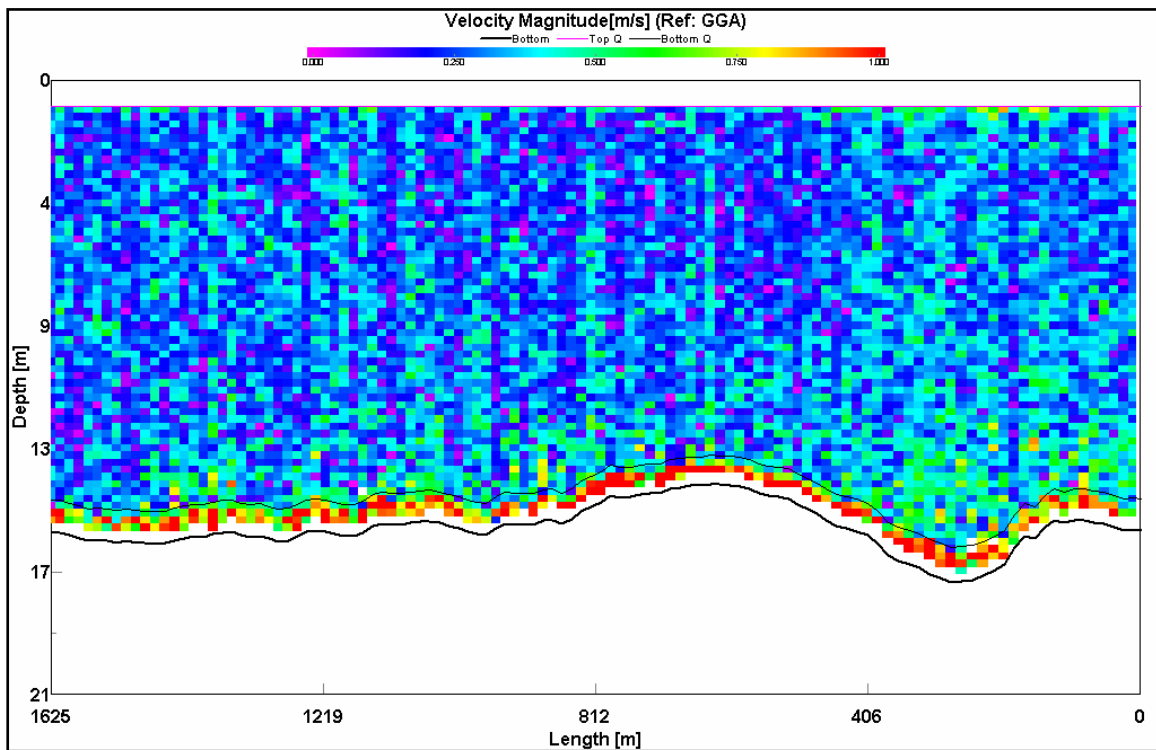


Figure E14. Transect 3 current velocity cross sections, 11 November 2004, 1545 GMT.

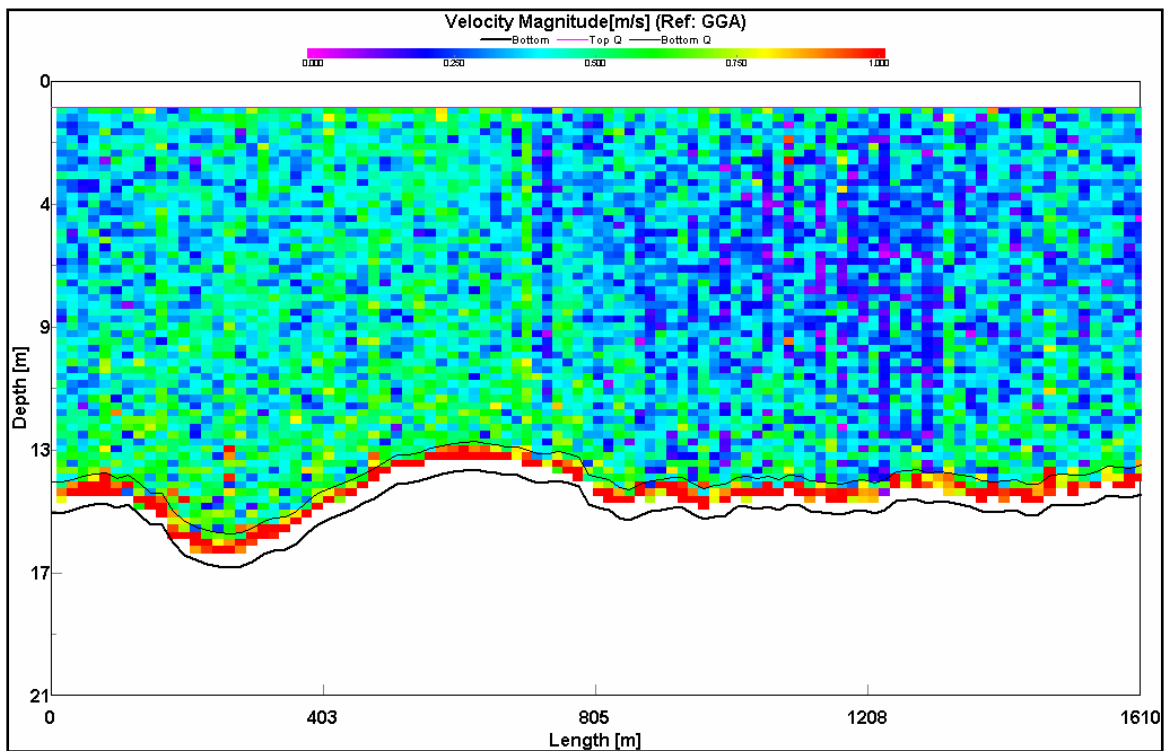


Figure E15. Transect 3 current velocity cross sections, 11 November 2004, 1649 GMT.

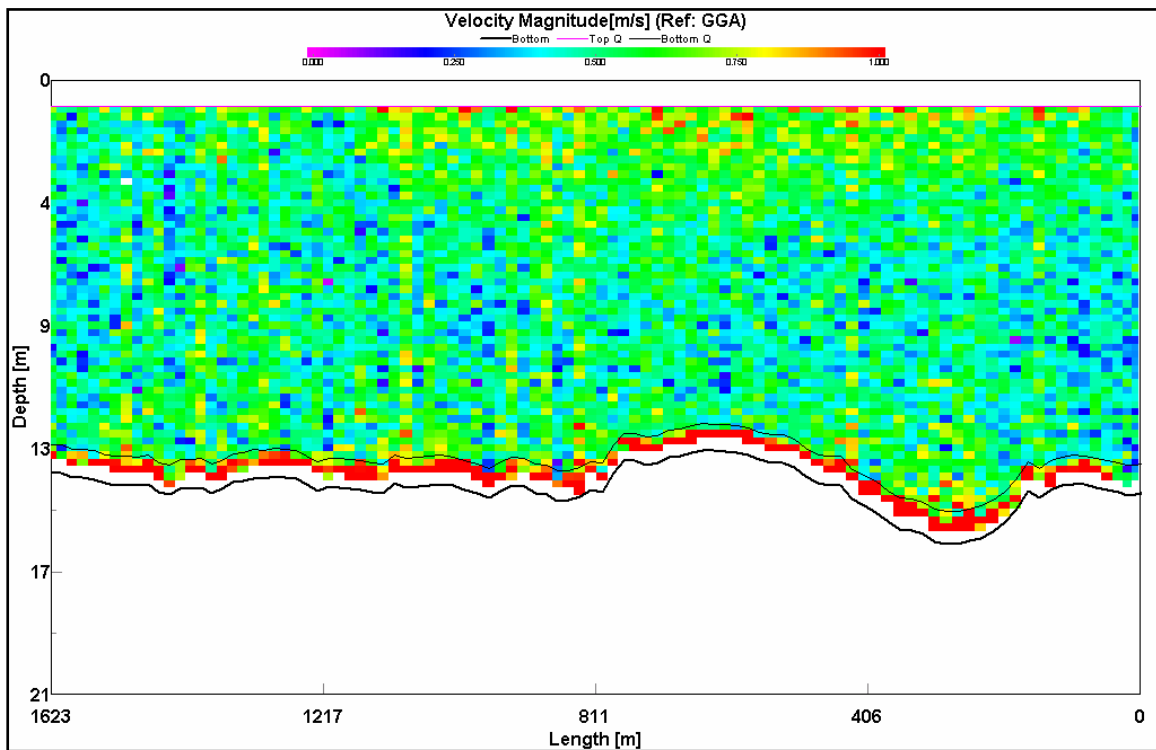


Figure E16. Transect 3 current velocity cross sections, 11 November 2004, 1748 GMT.

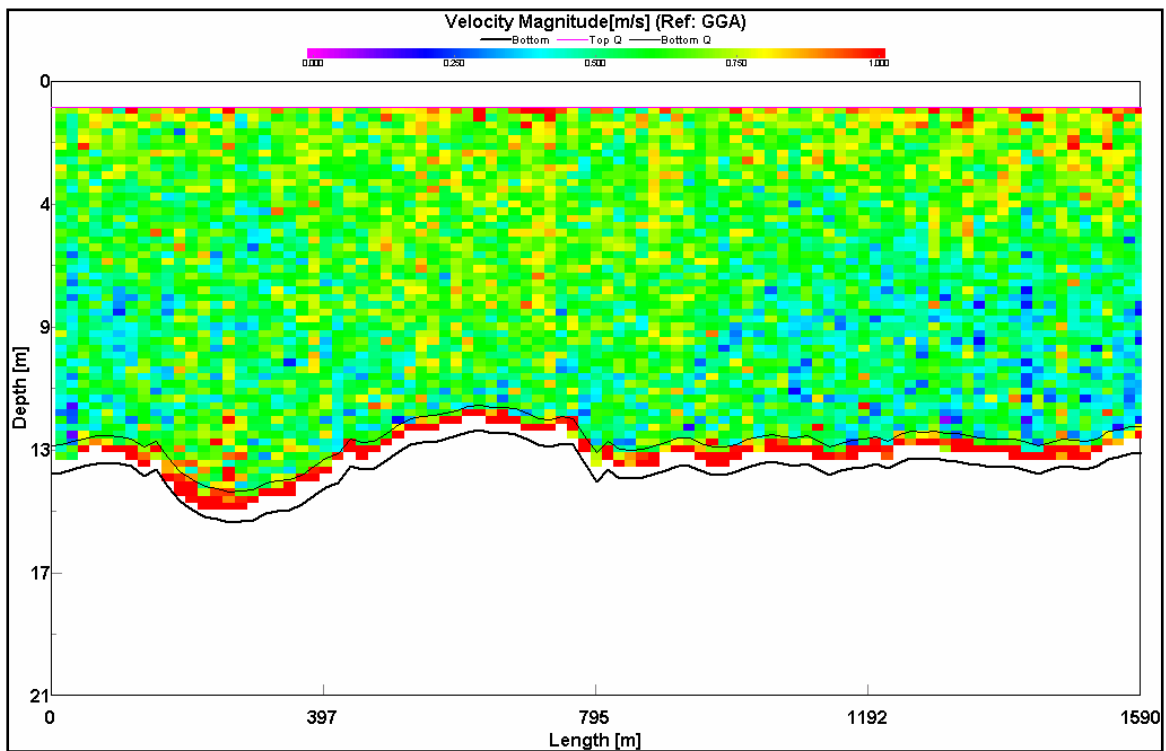


Figure E17. Transect 3 current velocity cross sections, 11 November 2004, 1851 GMT.

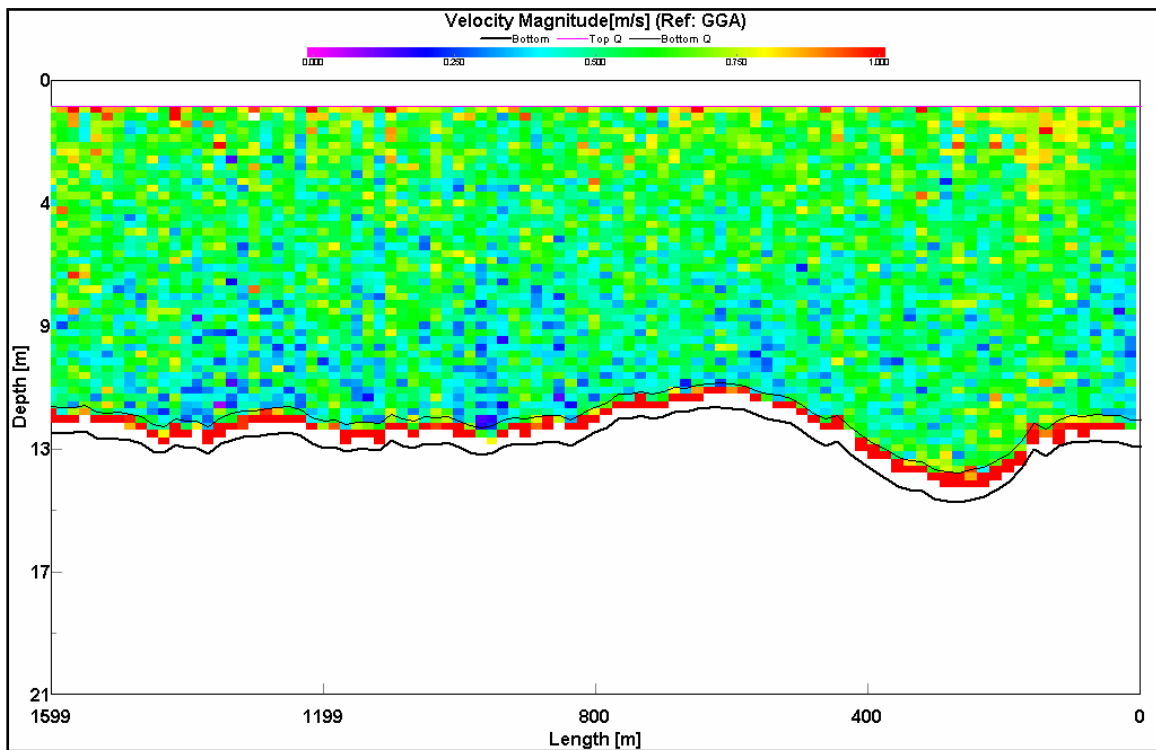


Figure E18. Transect 3 current velocity cross sections, 11 November 2004, 1951 GMT.

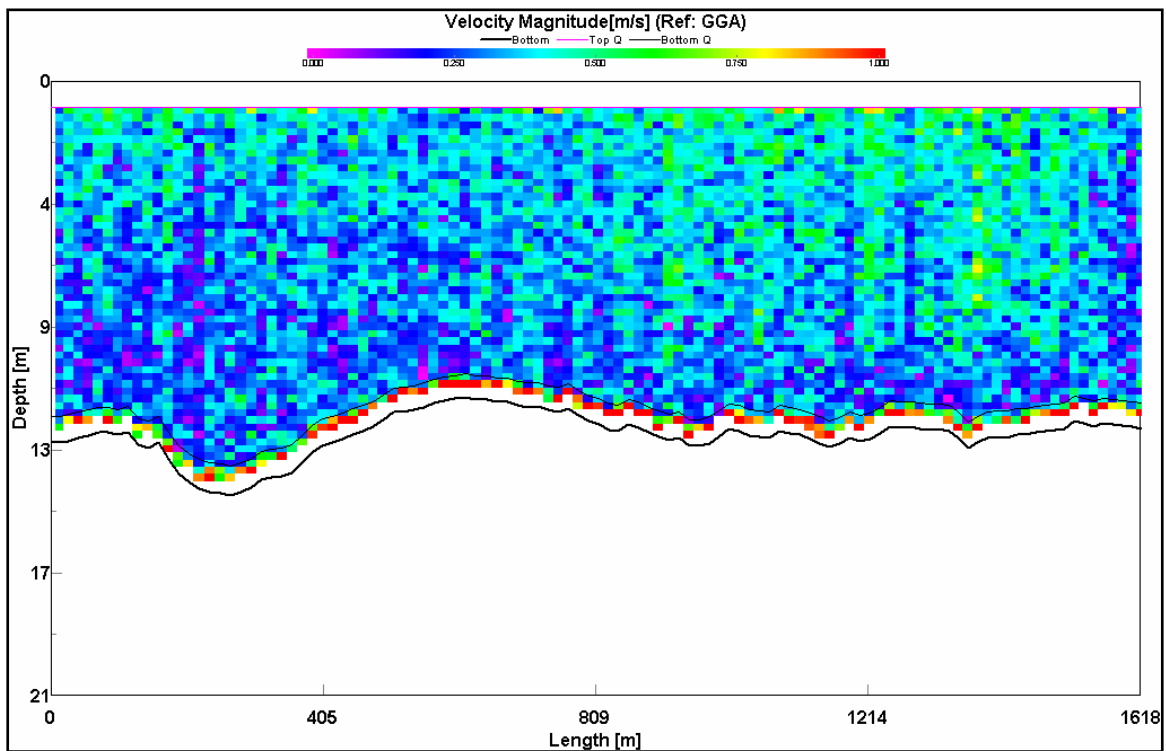


Figure E19. Transect 3 current velocity cross sections, 11 November 2004, 2055 GMT.

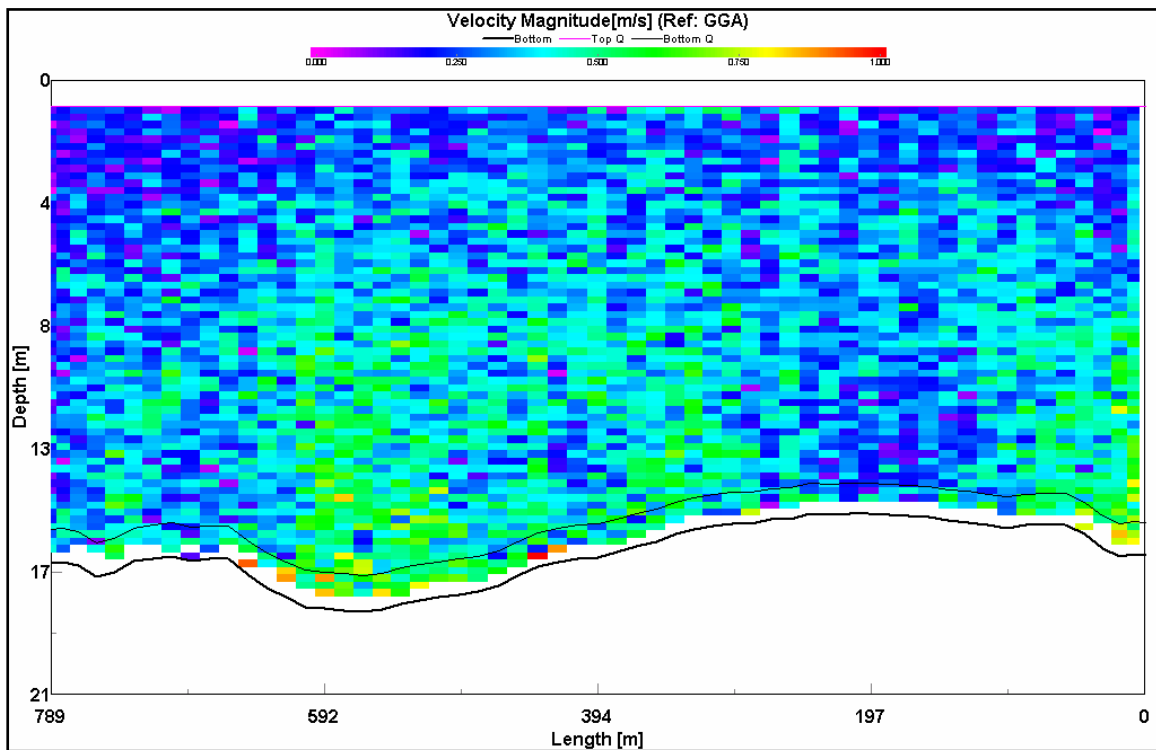


Figure E20. Transect 3 current velocity cross sections, 8 February 2005, 1520 GMT.

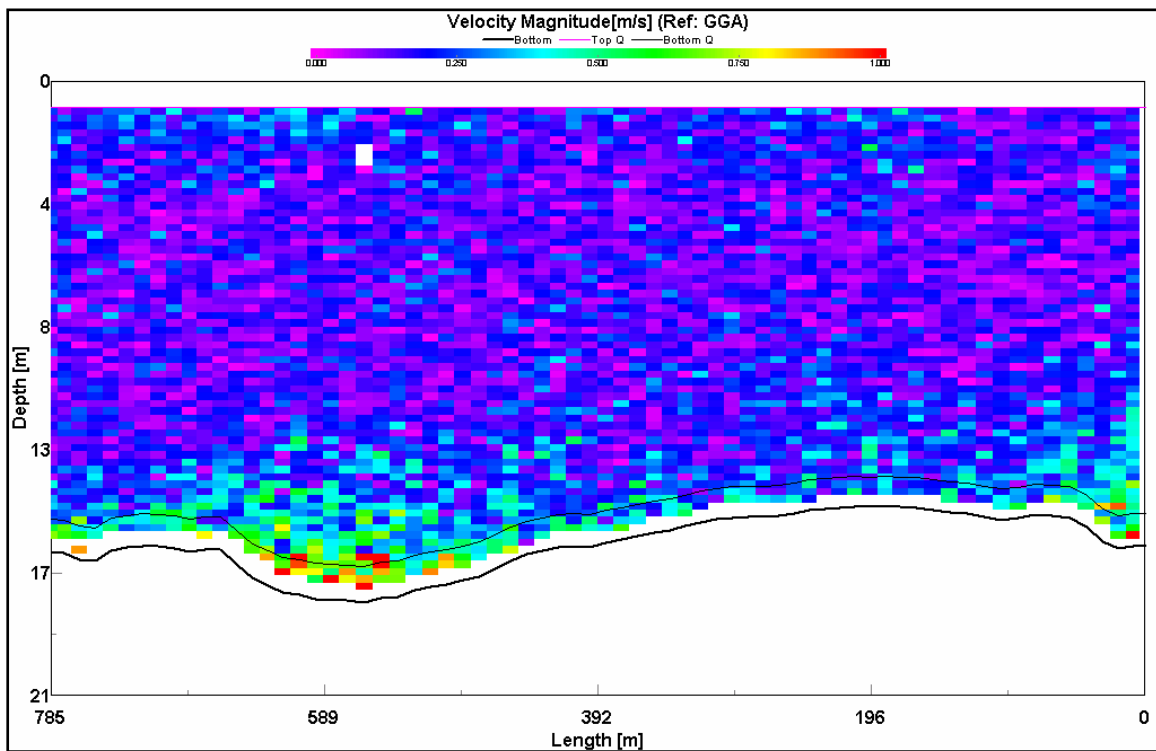


Figure E21. Transect 3 current velocity cross sections, 8 February 2005, 1636 GMT.

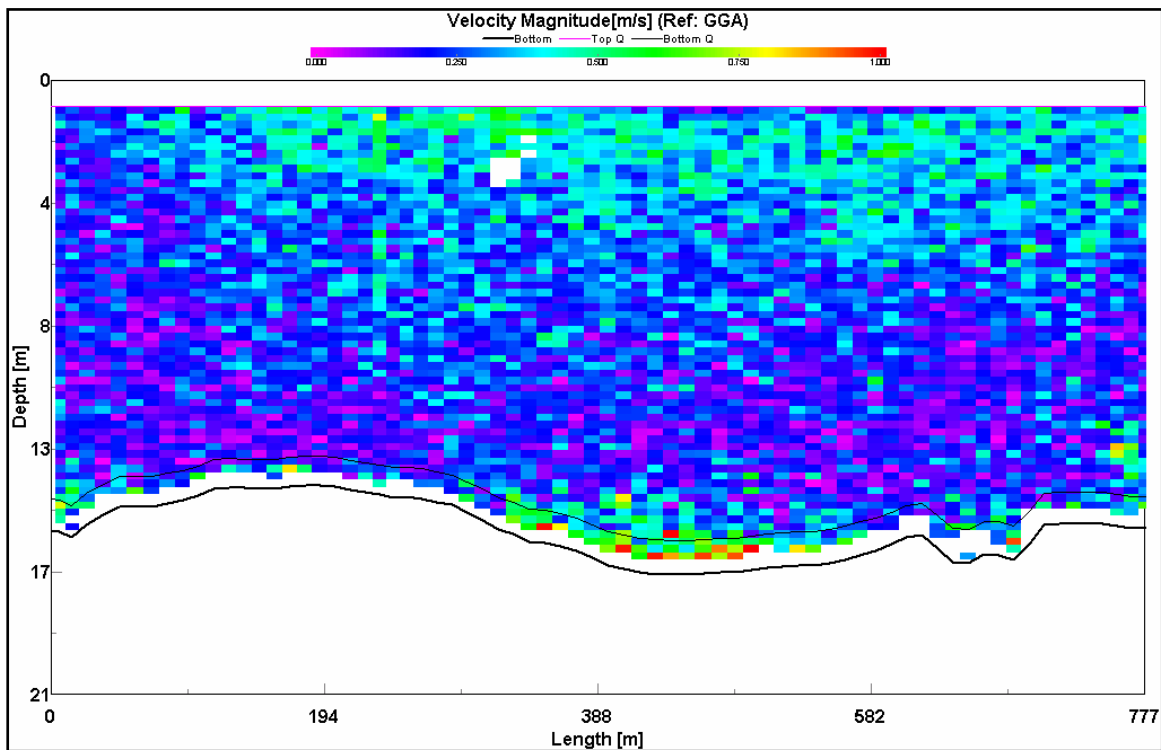


Figure E22. Transect 3 current velocity cross sections, 8 February 2005, 1747 GMT.

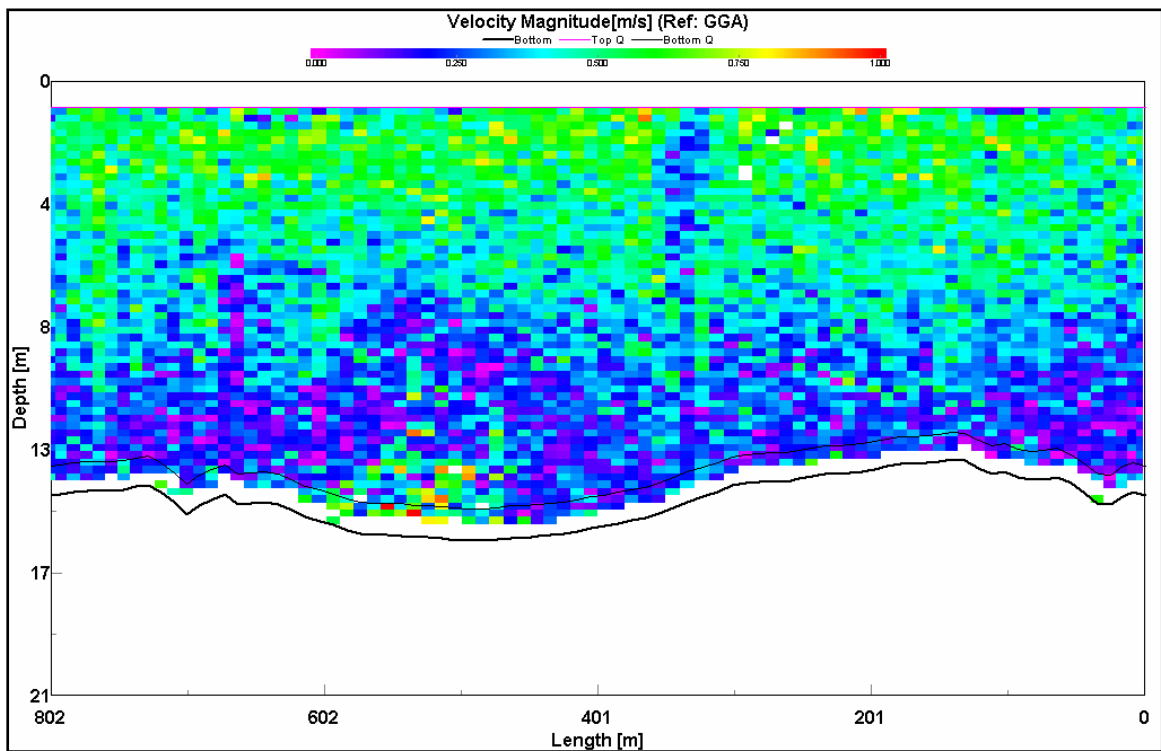


Figure E23. Transect 3 current velocity cross sections, 8 February 2005, 1909 GMT.

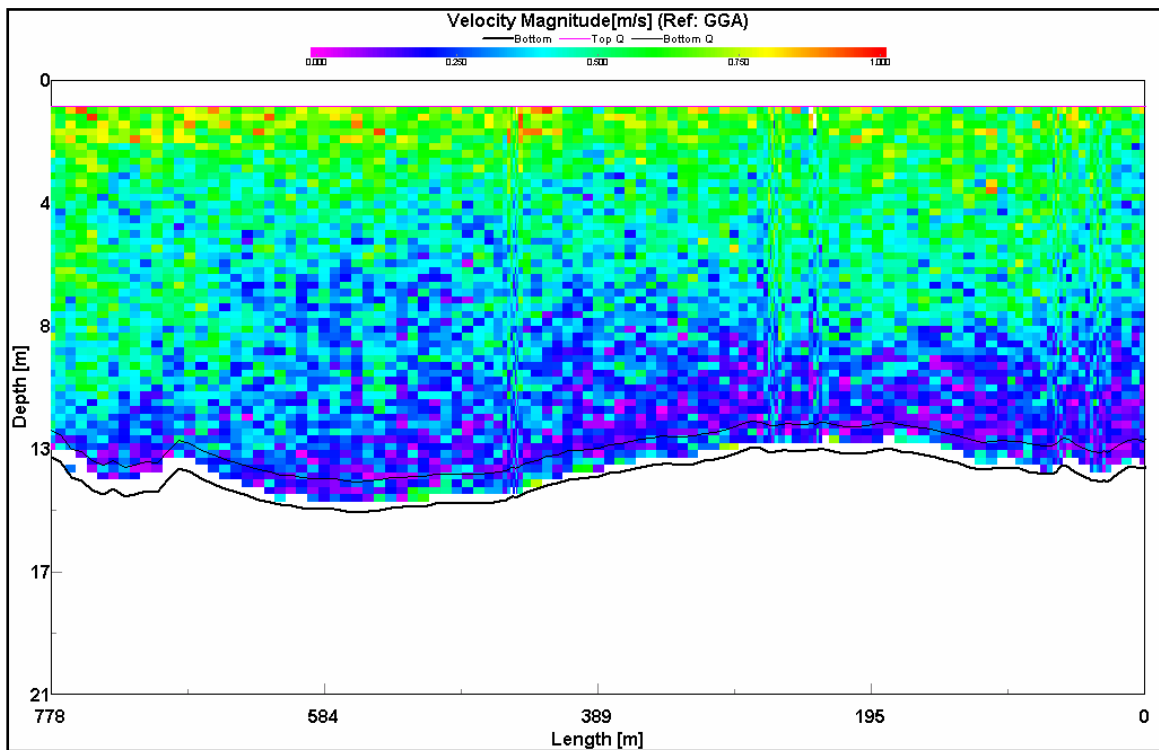


Figure E24. Transect 3 current velocity cross sections, 8 February 2005, 2012 GMT.

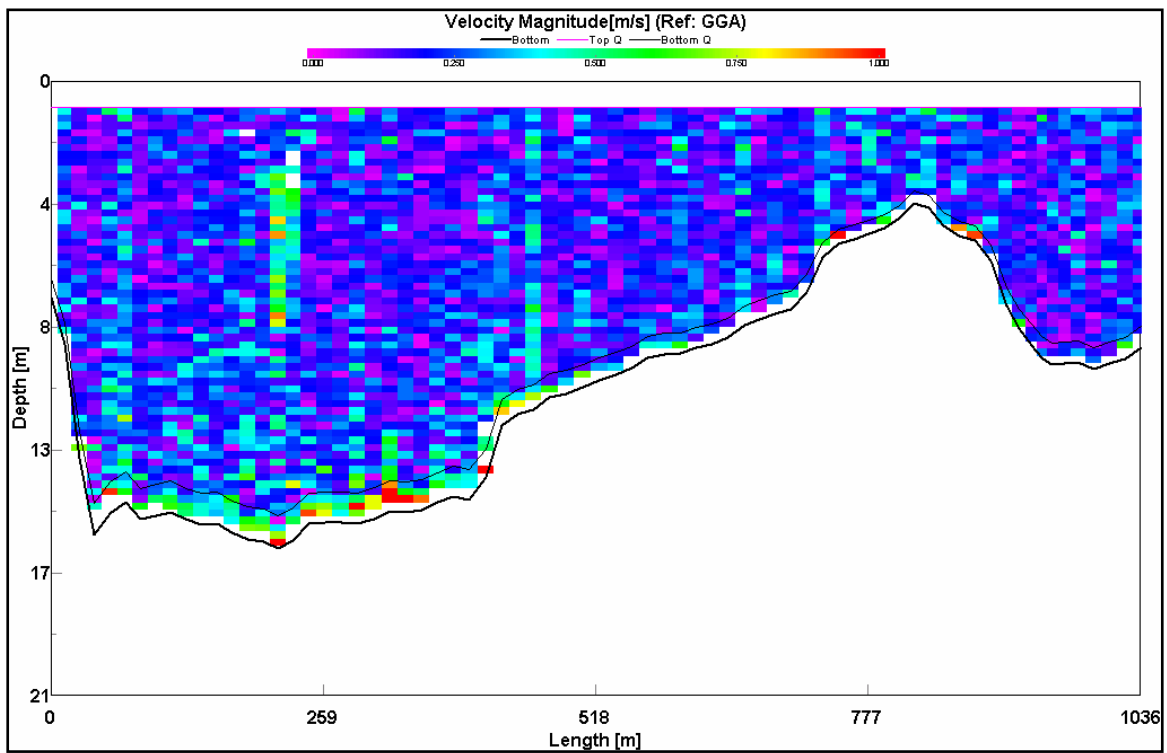


Figure E25. Transect 4 current velocity cross sections, 11 November 2004, 1359 GMT.

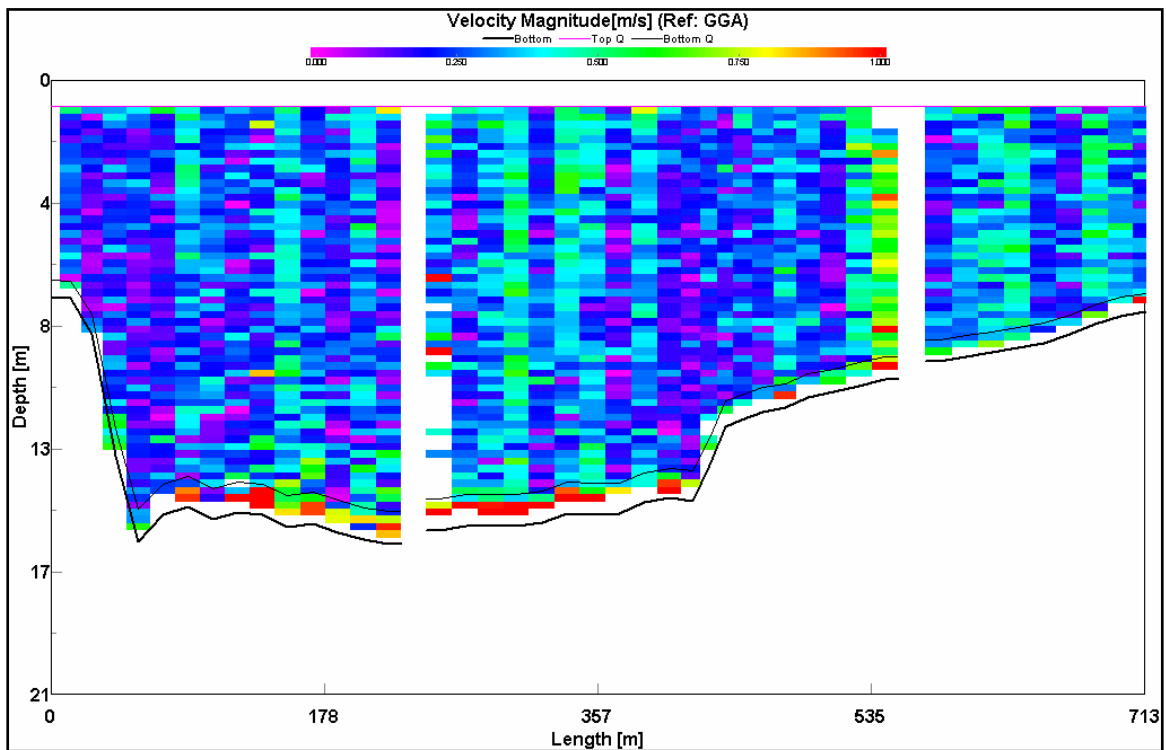


Figure E26. Transect 4 current velocity cross sections, 11 November 2004, 1450 GMT.

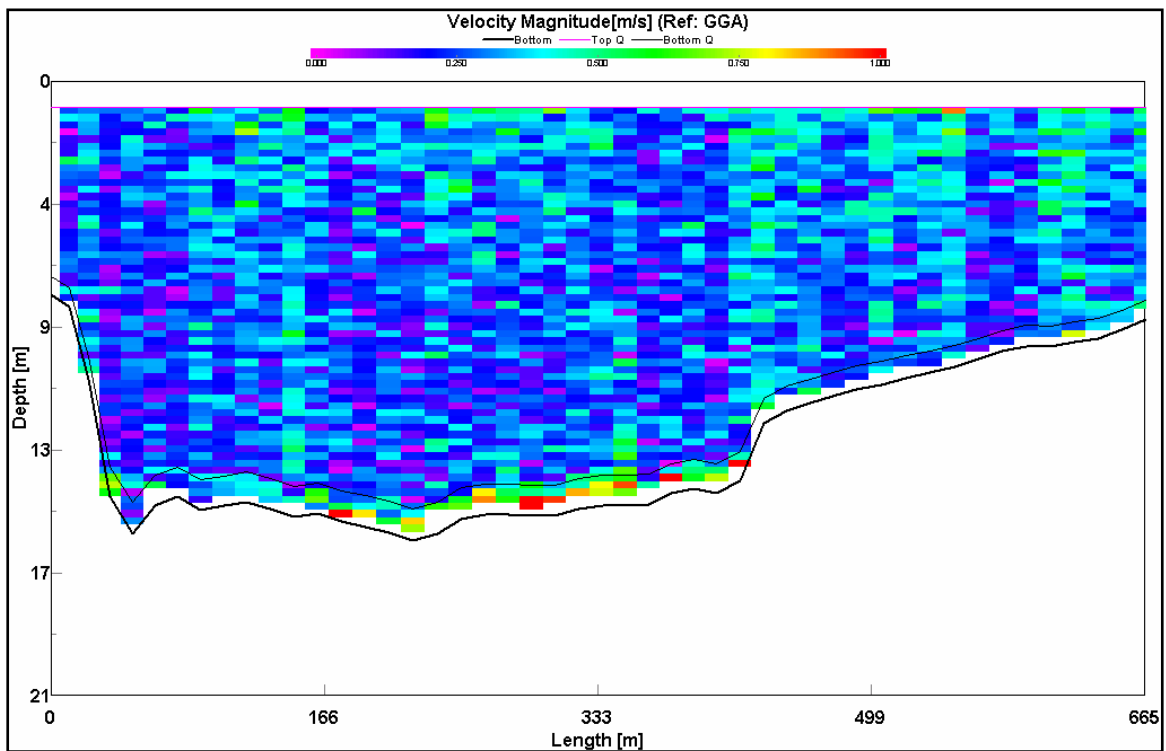


Figure E27. Transect 4 current velocity cross sections, 11 November 2004, 1528 GMT.

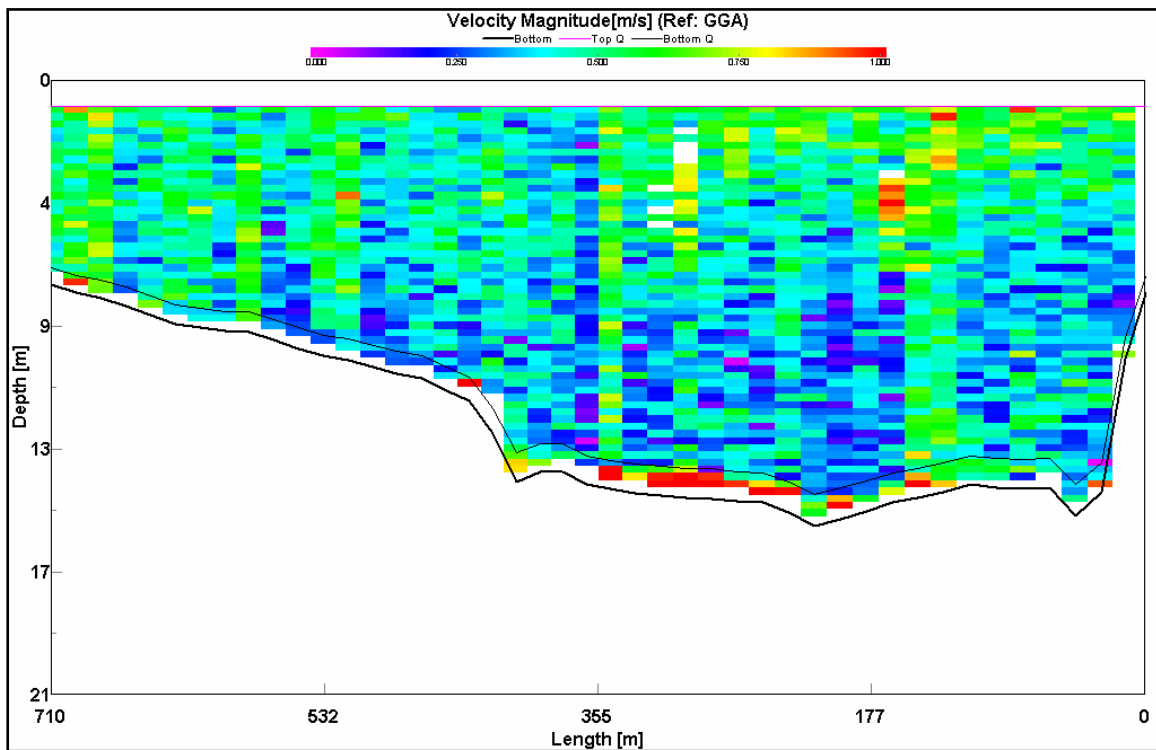


Figure E28. Transect 4 current velocity cross sections, 11 November 2004, 1632 GMT.

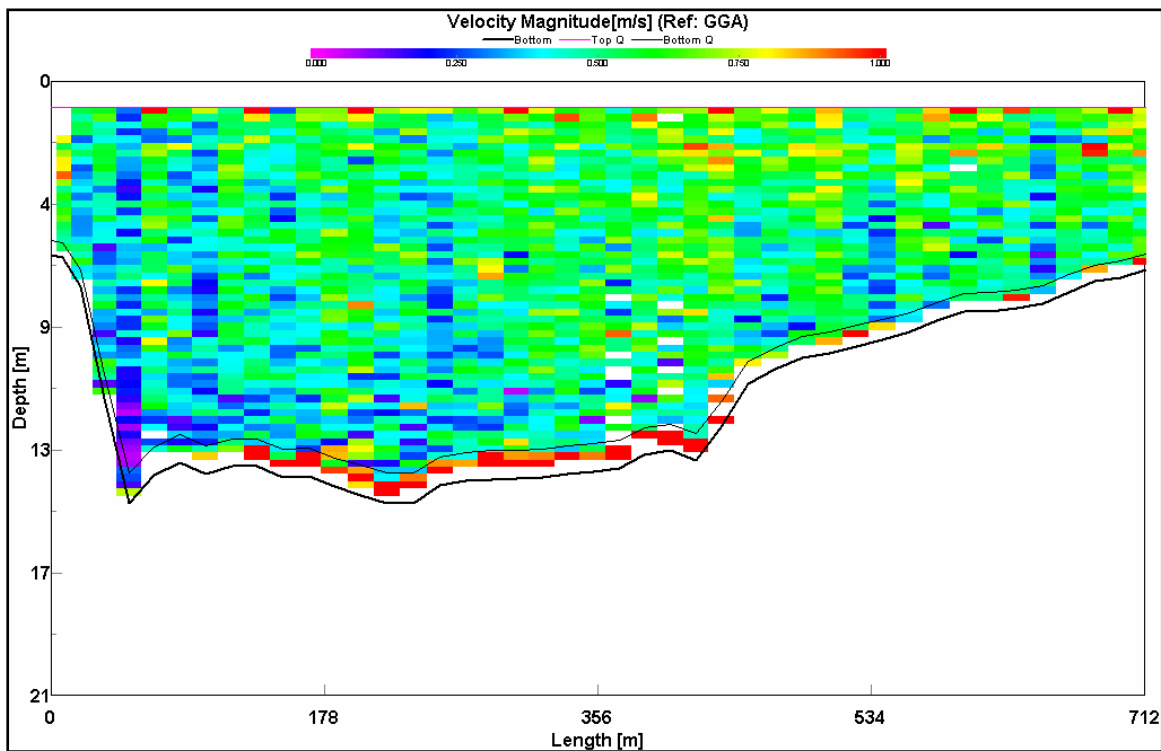


Figure E29. Transect 4 current velocity cross sections, 11 November 2004, 1736 GMT.

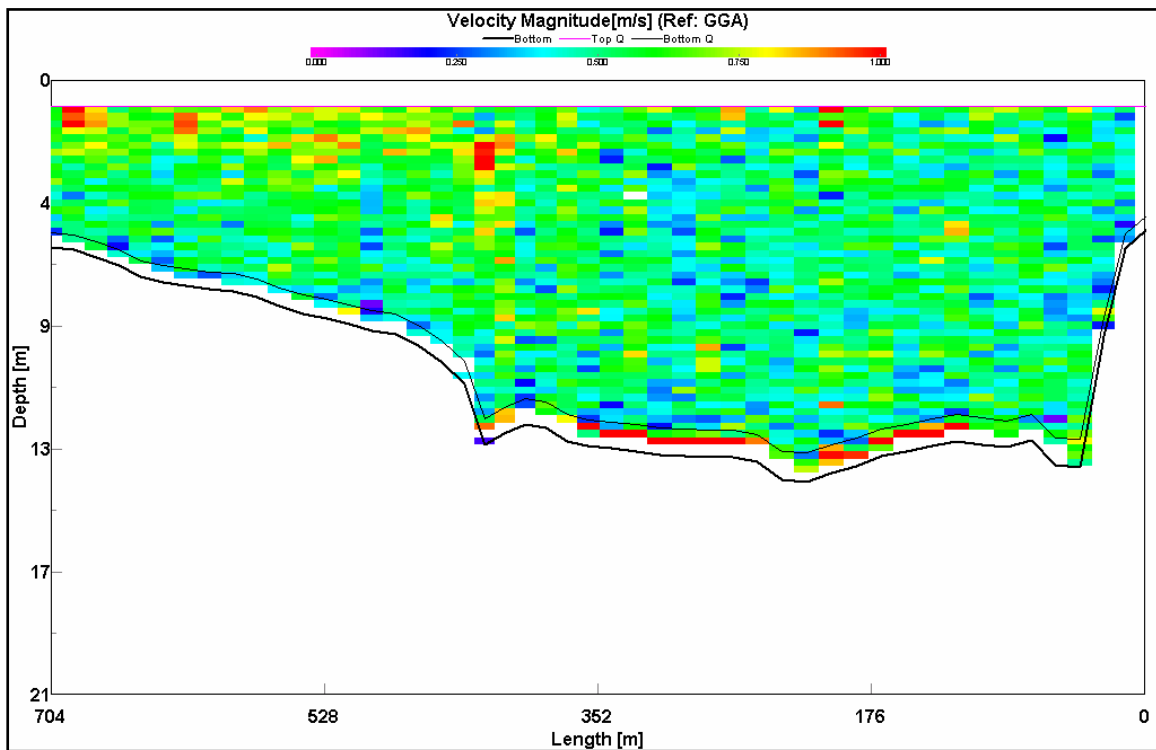


Figure E30. Transect 4 current velocity cross sections, 11 November 2004, 1836 GMT.

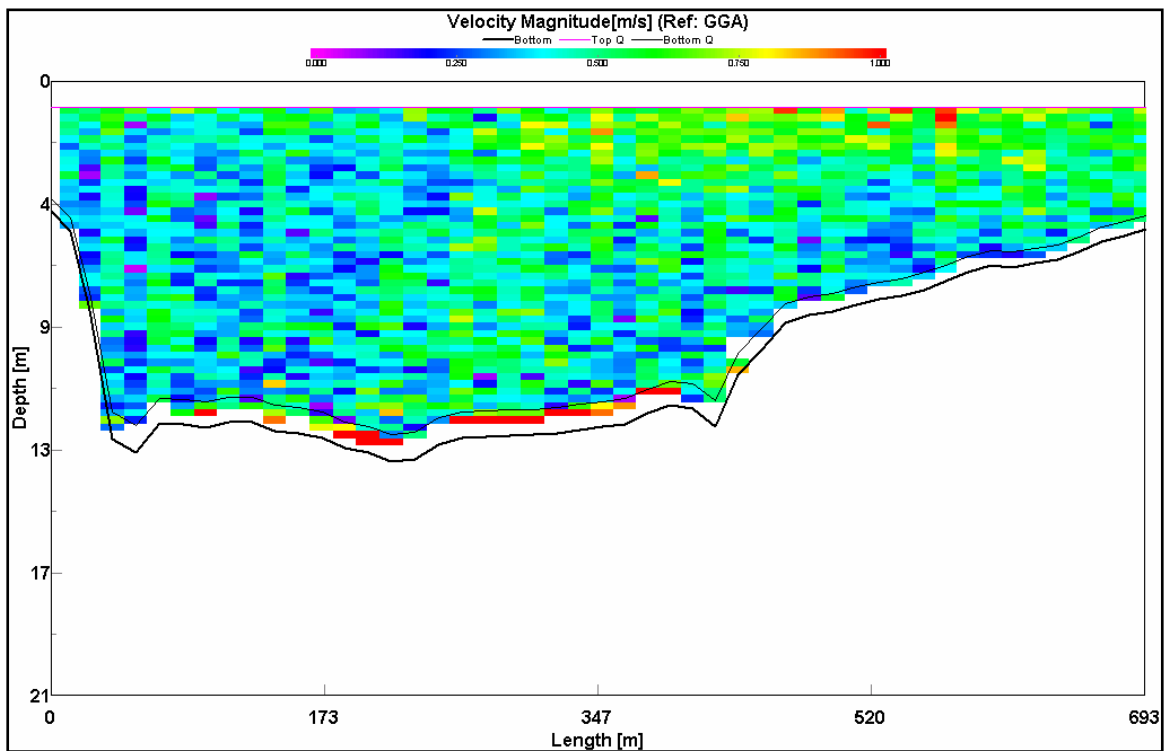


Figure E31. Transect 4 current velocity cross sections, 11 November 2004, 1936 GMT.

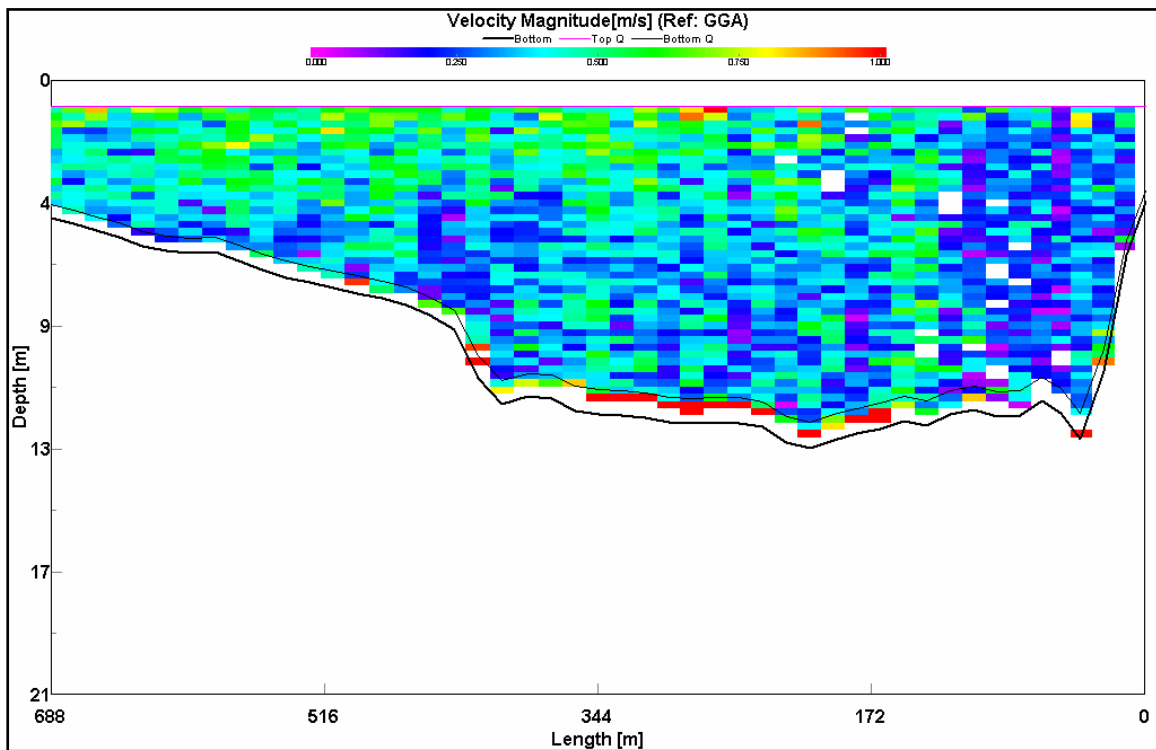


Figure E32. Transect 4 current velocity cross sections, 11 November 2004, 2039 GMT.

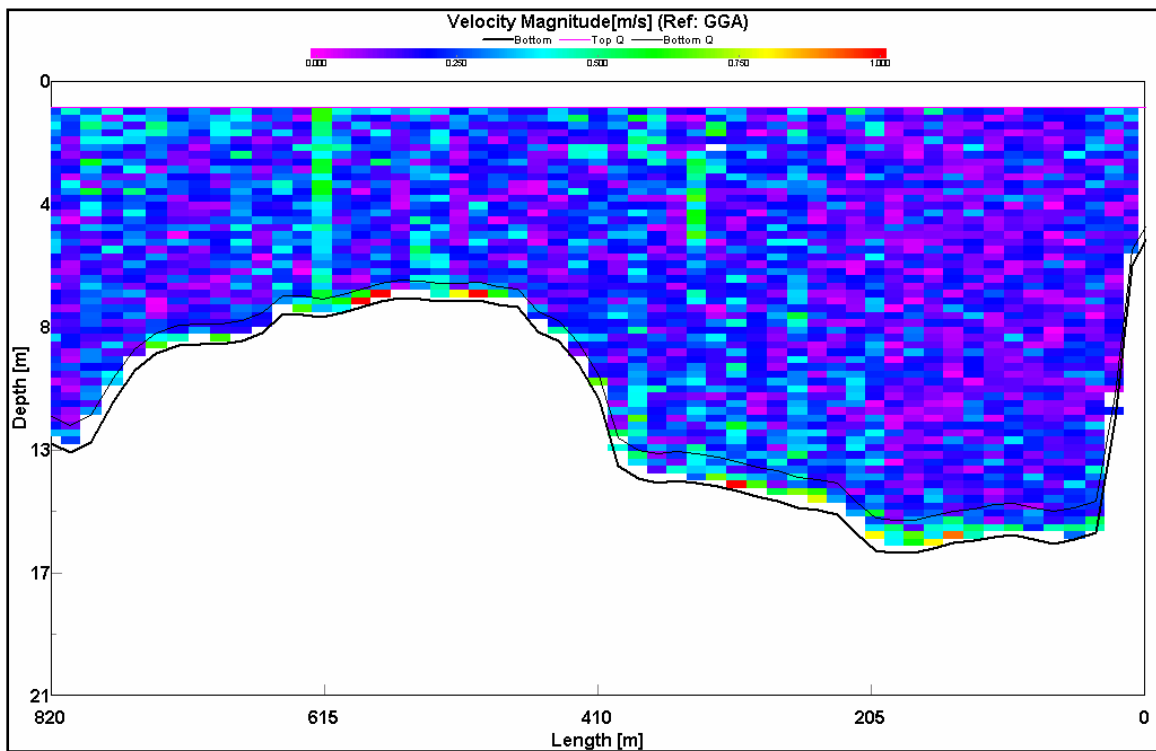


Figure E33. Transect 5 current velocity cross sections, 11 November 2004, 1339 GMT.

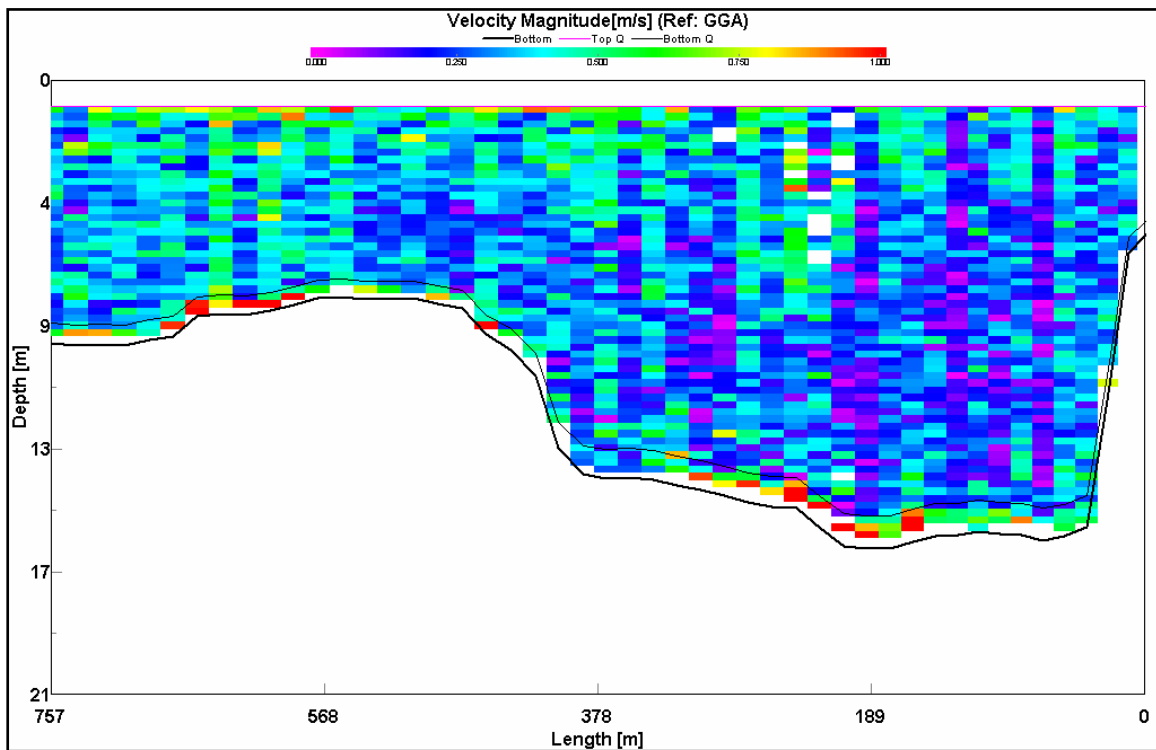


Figure E34. Transect 5 current velocity cross sections, 11 November 2004, 1514 GMT.

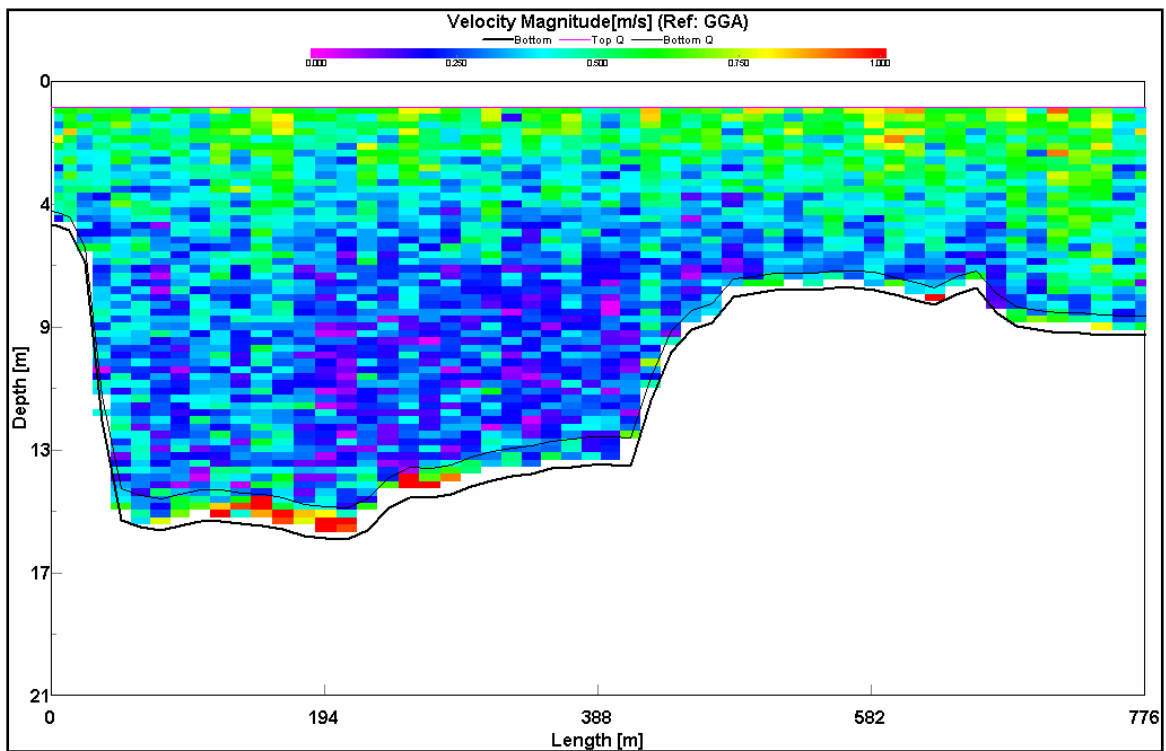


Figure E35. Transect 5 current velocity cross sections, 11 November 2004, 1616 GMT.

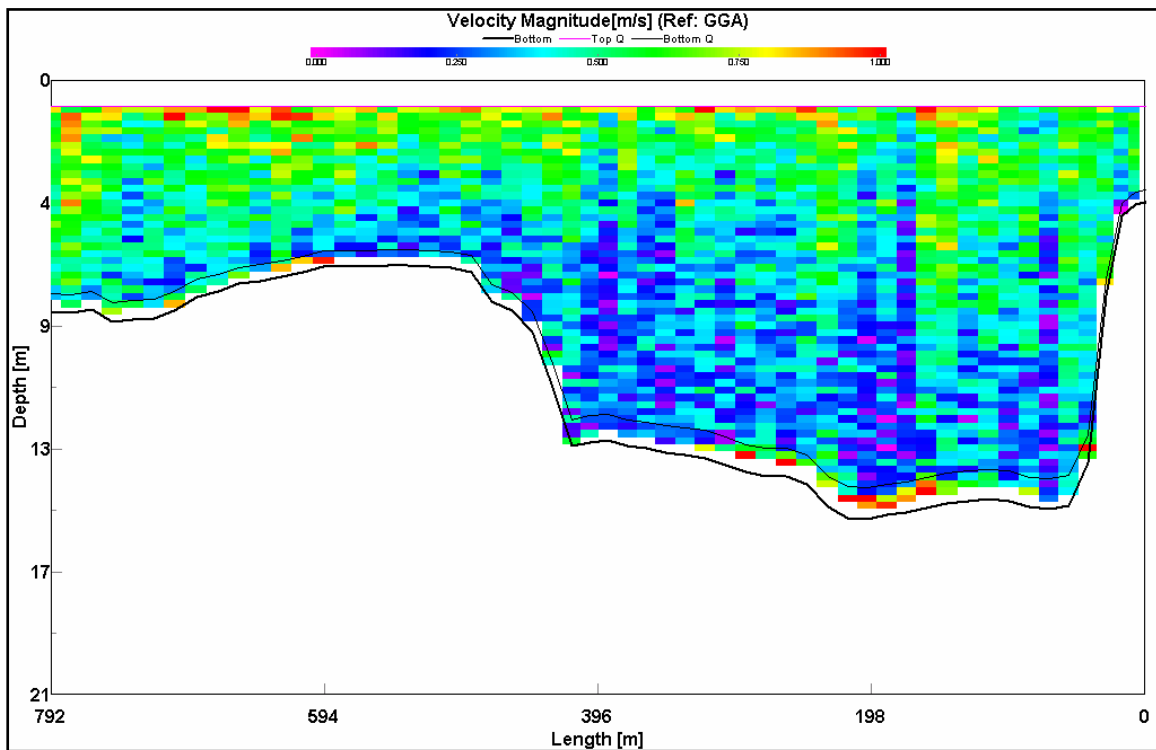


Figure E36. Transect 5 current velocity cross sections, 11 November 2004, 1721 GMT.

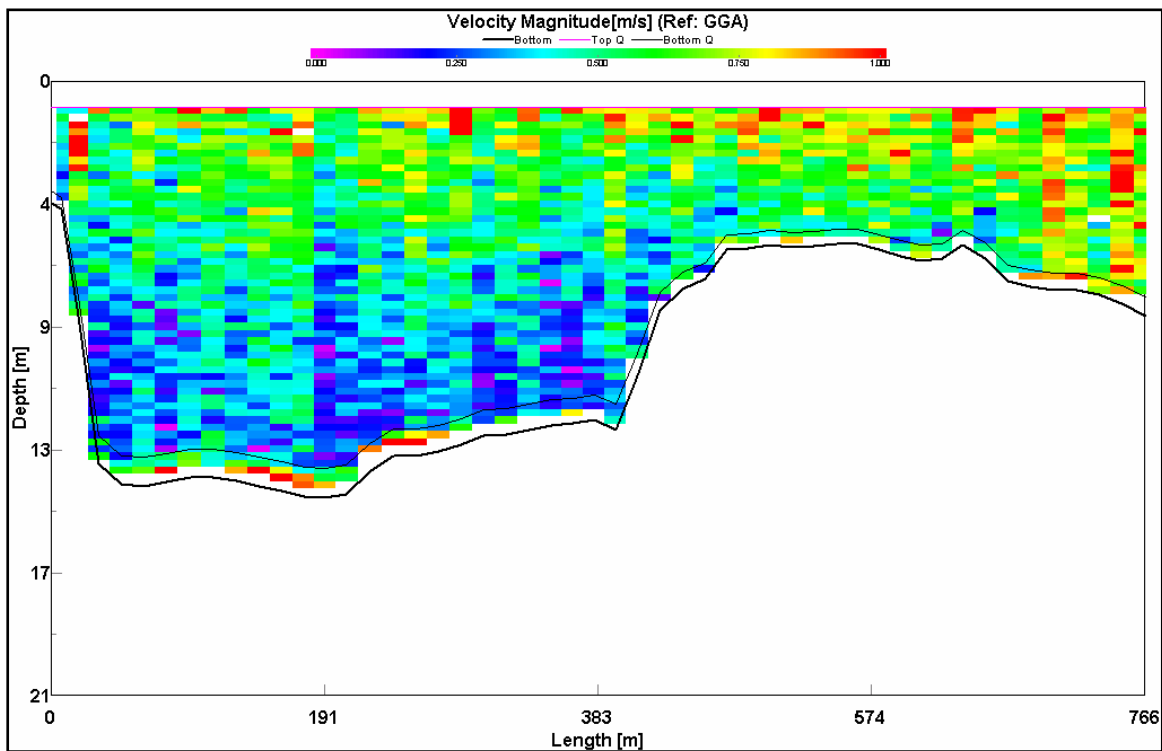


Figure E37. Transect 5 current velocity cross sections, 11 November 2004, 1822 GMT.

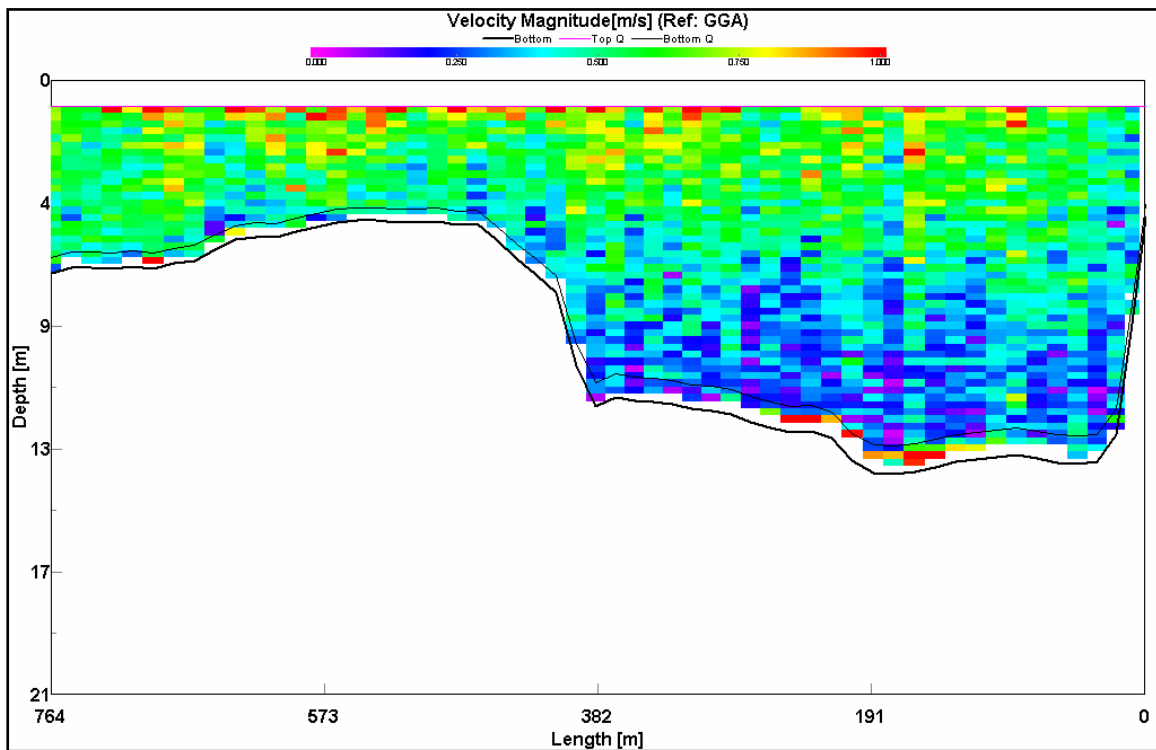


Figure E38. Transect 5 current velocity cross sections, 11 November 2004, 1922 GMT.

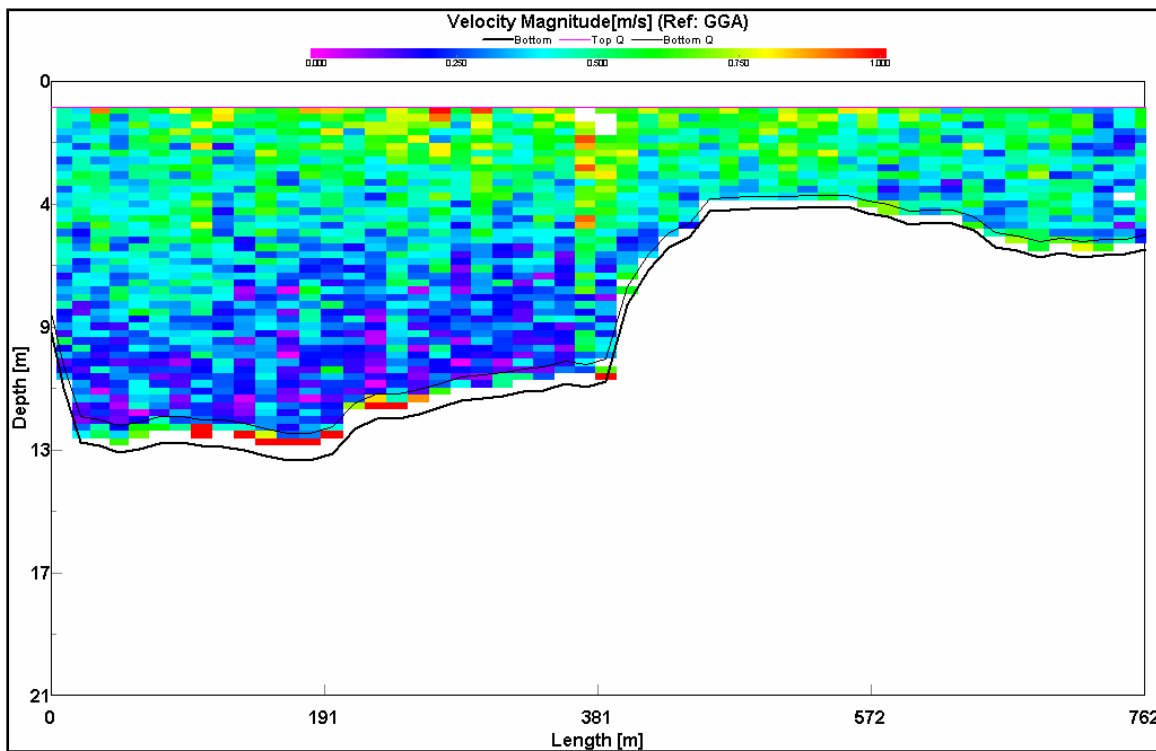


Figure E39. Transect 5 current velocity cross sections, 11 November 2004, 2022 GMT.

## Appendix F: Wind Measurement Plots

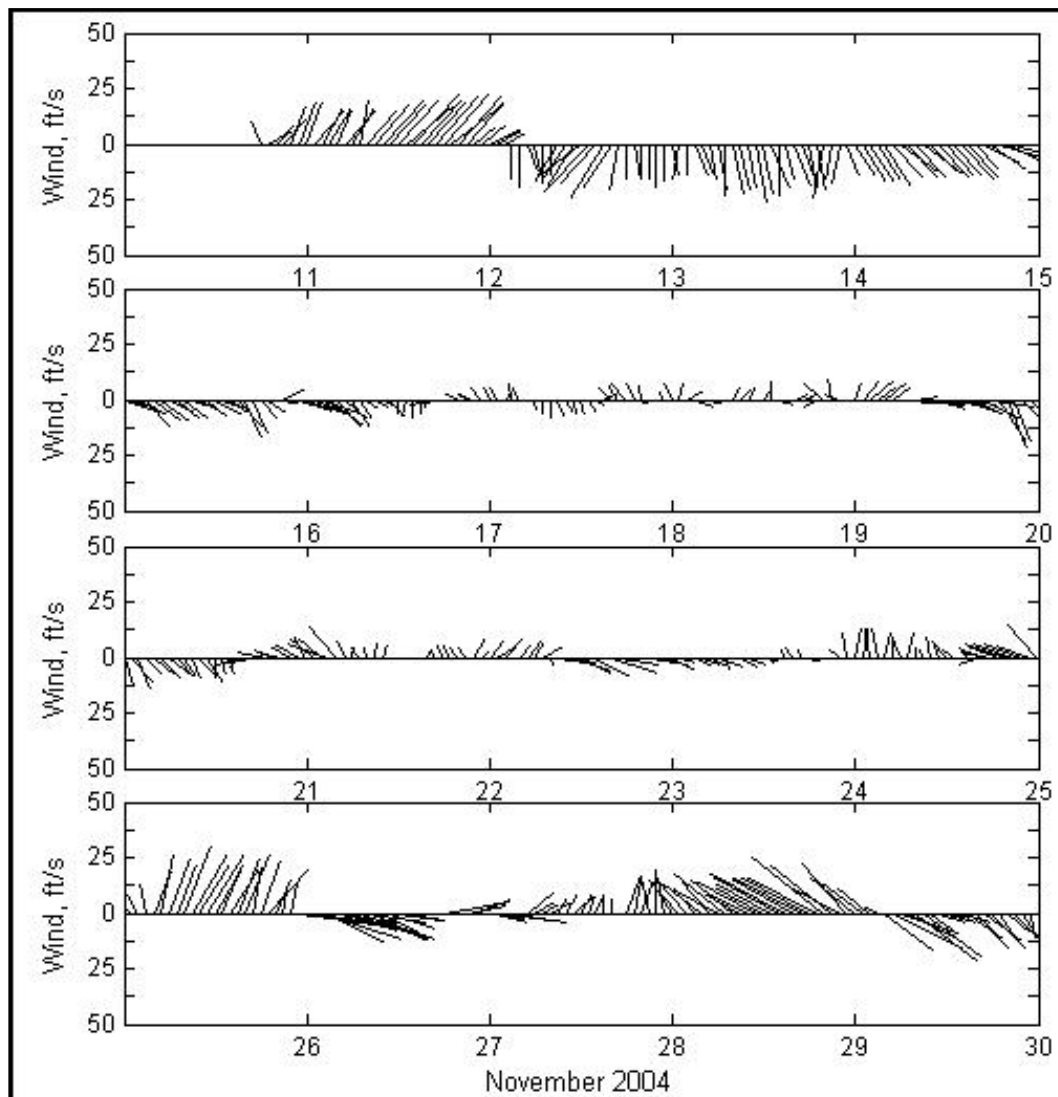


Figure F1. Wind measurement plots at Logan Airport, November 2004.

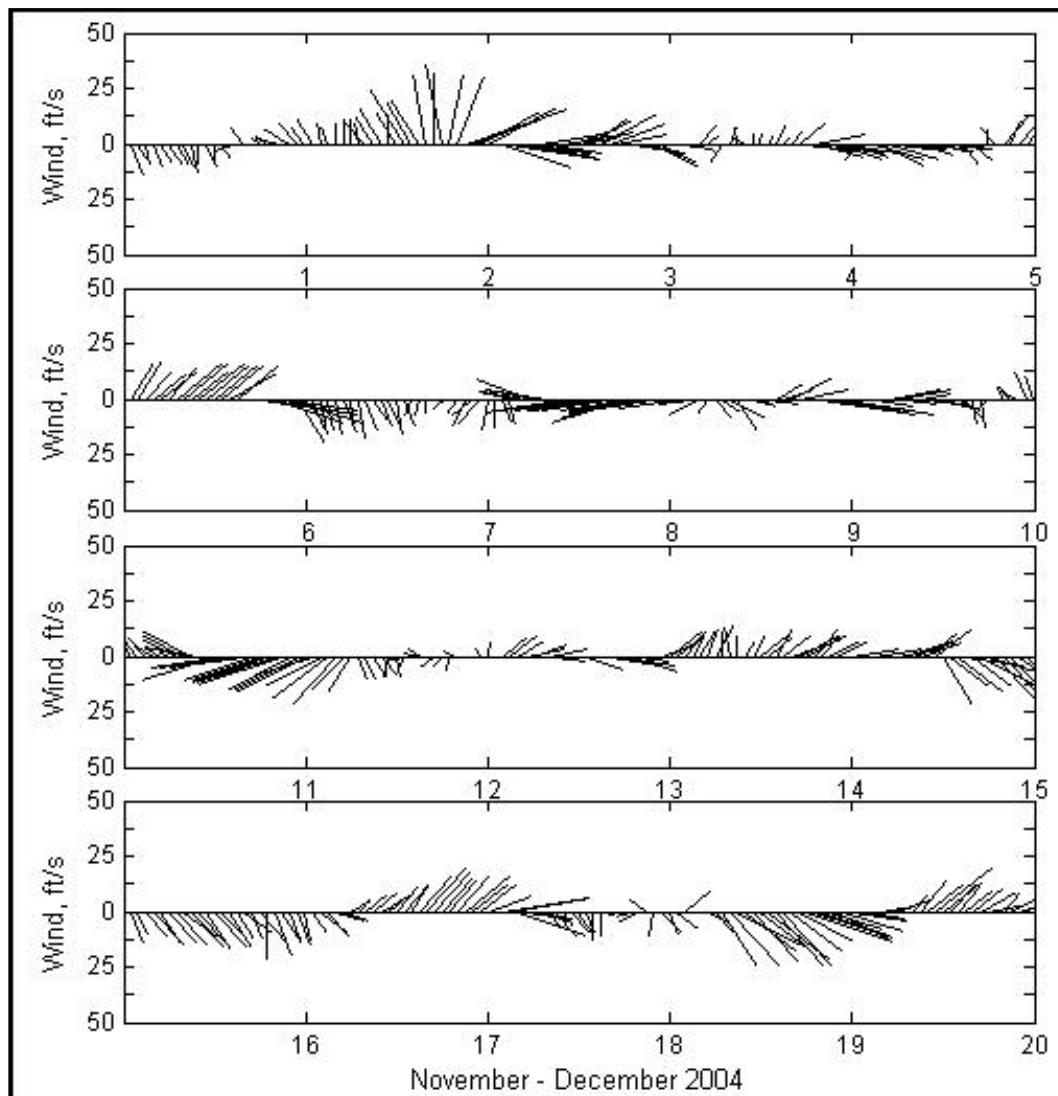


Figure F2. Wind measurement plots at Logan Airport, November-December 2004.

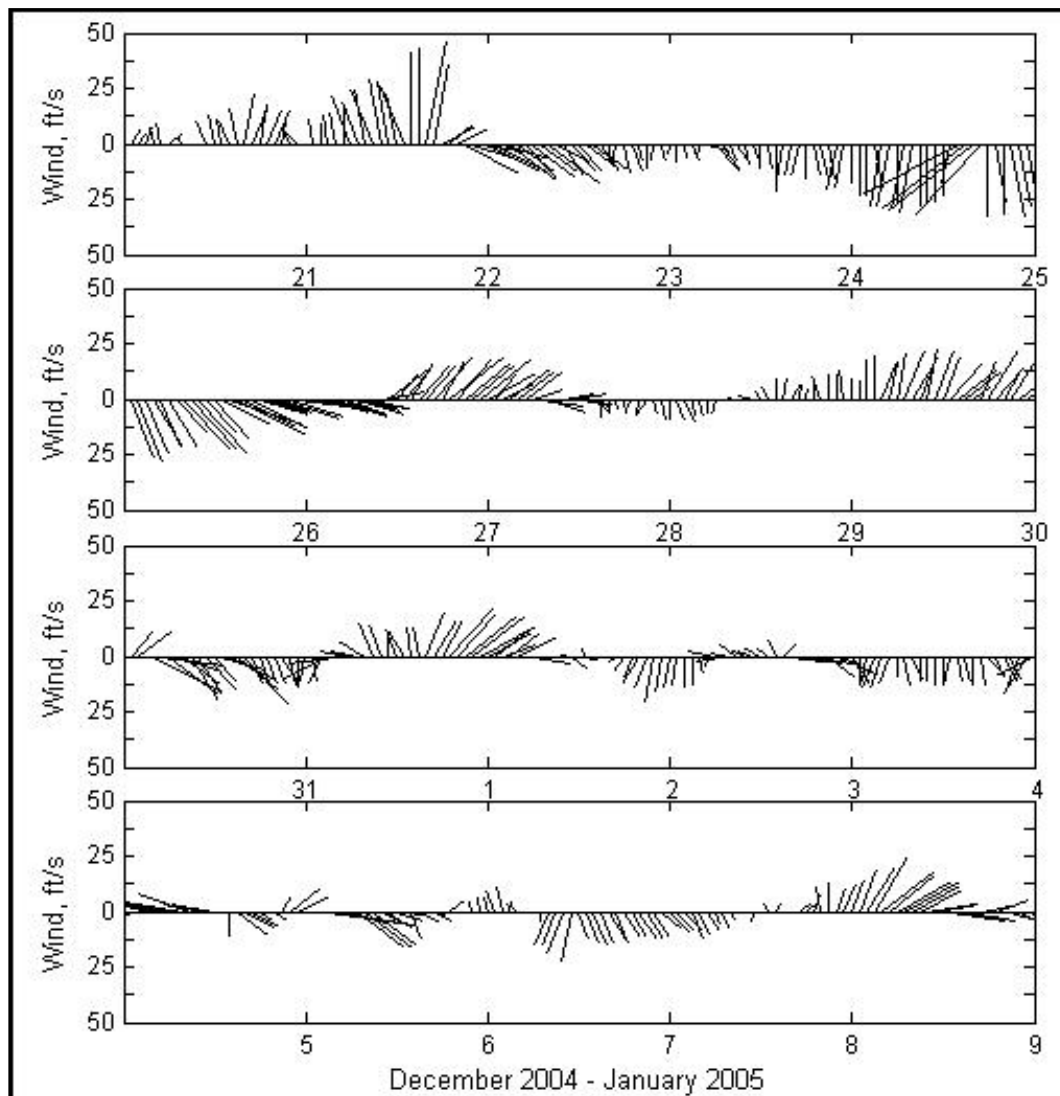


Figure F3. Wind measurement plots at Logan Airport, December 2004–January 2005.

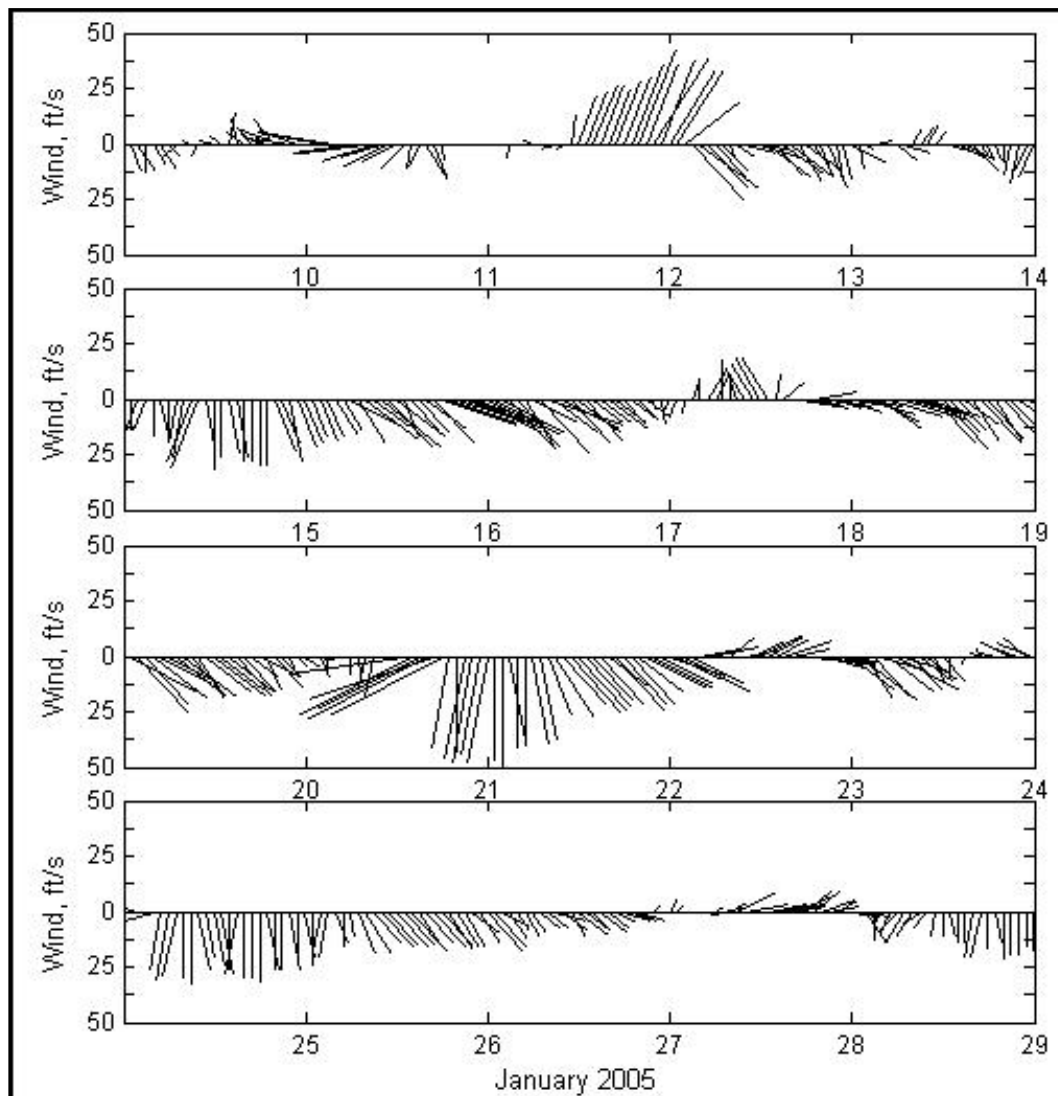


Figure F4. Wind measurement plots at Logan Airport, January 2005.

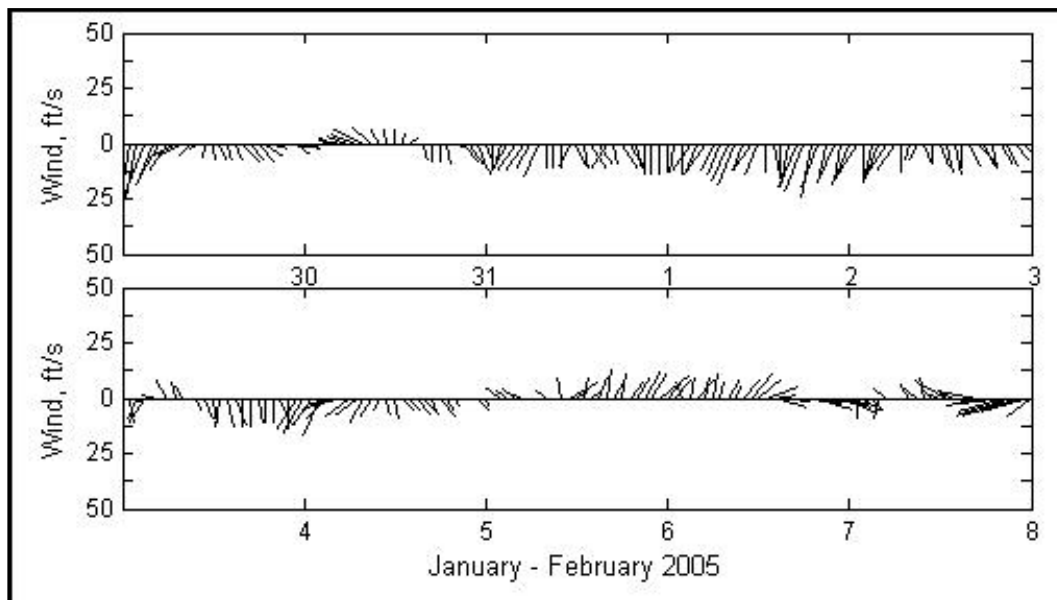


Figure F5. Wind measurement plots at Logan Airport, January-February 2005.

## Appendix G: Folder Structure of Project DVD

Table G1. Folder structure of project DVD.

<b>Boston Harbor Field Data Collection Program</b>	
	Readme.txt (Table G1)
	<b>Documents</b>
	Report Contents .doc (report table of contents)
	Report.doc (the final report without the appendices)
	Appendix A.doc (Scope of Work)
	Appendix B.doc (Water-level Measurements Plots)
	Appendix C.doc (Moored Current Measurements Plots)
	Appendix D.doc (Transect Current Surveys, Depth-averaged Current Plots)
	Appendix E.doc (Transect Current Surveys, Current Velocity Cross-sections Plots)
	Appendix F.doc (Wind Measurements Plots)
	Appendix G.doc (Folder Structure on Project DVD)
	Appendix E.doc (Data File Formats)
	First Field Report.doc ("Instrumentation Deployment and Tidal-Current Survey – 8–12 November 2004")
	Second Field Report.doc ("Instrumentation Recovery and Tidal-Current Transect Survey – 6–9 February 2005")
	<b>Plots</b>
	Readme.txt (Figures 2 and 12, showing the instrument locations and designations, and the transect locations)
	<b>Water-Level Measurements</b>
	TG1_1.jpeg (time series plot of water levels from TG1 – 10– 30 November 2004)
	TG1_2.jpeg (time series plot of water levels from TG1 – 30 November 30 – 20 December 2004)
	TG1_3.jpeg (time series plot of water levels from TG1 – 20 December 2004 – 9 January 2005)
	TG1_4.jpeg (time series plot of water levels from TG1 – 9–29 January 2005)
	TG1_5.jpeg (time series plot of water levels from TG1 – 29 January – 8 February 2005)
	TG2_1.jpeg (time series plot of water levels from TG2 – 10–30 November 2004)
	TG2_2.jpeg (time series plot of water levels from TG2 – 30 November – 20 December 2004)
	TG2_3.jpeg (time series plot of water levels from TG2 – 20 December 2004 – 9 January 2005)
	TG2_4.jpeg (time series plot of water levels from TG2 – 9–29 January 2005)
(Sheet 1 of 7)	

Table G1. (Continued)

**Water-Level Measurements (continued)**

TG2\_5.jpeg (time series plot of water levels from TG2 – 29 January – 8 February 2005)

TG3\_1.jpeg (time series plot of water levels from TG3 – 10–30 November 2004)

TG3\_2.jpeg (time series plot of water levels from TG3 – 30 November – 20 December 2004)

TG3\_3.jpeg (time series plot of water levels from TG3 – 20 December 2004 – 9 January 2005)

TG3\_4.jpeg (time series plot of water levels from TG3 – 9–29 January 2005)

TG3\_5.jpeg (time series plot of water levels from TG3 – 29 January – 8 February 2005)

TG4\_1.jpeg (time series plot of water levels from TG4 – 10–30 November 2004)

TG4\_2.jpeg (time series plot of water levels from TG4 – 30 November – 20 December 2004)

TG4\_3.jpeg (time series plot of water levels from TG4 – 20 December 2004 – 9 January 2005)

TG4\_4.jpeg (time series plot of water levels from TG4 – 9–29 January 2005)

TG4\_5.jpeg (time series plot of water levels from TG4 – 29 January – 8 February 2005)

NOAA\_1.jpeg (time series plot of water levels from the NOAA tide gage – 10–30 November 2004)

NOAA\_2.jpeg (time series plot of water levels from the NOAA tide gage – 30 November – 20 December 2004)

NOAA\_3.jpeg (time series plot of water levels from the NOAA tide gage – 20 December 2004 – 9 January 2005)

NOAA\_4.jpeg (time series plot of water levels from the NOAA tide gage – 9–29 January 2005)

NOAA\_5.jpeg (time series plot of water levels from the NOAA tide gage – 29 January – 8 February 2005)

**Moored Current Measurements**

CM2\_1.jpeg (time series plot of depth-averaged currents from CM2 – 10–30 November 2004)

CM2\_2.jpeg (time series plot of depth-averaged currents from CM2 – 30 November – 20 December 2004)

CM2\_3.jpeg (time series plot of depth-averaged currents from CM2 – 20 December 2004 – 9 January 2005)

CM2\_4.jpeg (time series plot of depth-averaged currents from CM2 – 9–29 January 2005)

CM2\_5.jpeg (time series plot of depth-averaged currents from CM2 – 29 January – 8 February 2005)

Table G1. (Continued)

**Logan Airport Wind Measurements**

LA\_1.jpeg (time series plot of winds from Logan Airport –  
10–30 November 2004)

LA\_2.jpeg (time series plot of winds from Logan Airport –  
30 November – 20 December 2004)

LA\_3.jpeg (time series plot of winds from Logan Airport –  
20 December 2004 – 9 January 2005)

LA\_4.jpeg (time series plot of winds from Logan Airport –  
9–29 January 2005)

LA\_5.jpeg (time series plot of winds from Logan Airport –  
29 January – 8 February 2005)

**Current Transect Measurements**

Current Cross-Sections.doc (vertical profiles of current  
speed across each transect)

T4\_11\_11\_1321.jpeg (depth-averaged current velocities across  
transect T4 at 1321 (GMT) on 11 November 2004)

T5\_11\_11\_1339.jpeg (depth-averaged current velocities across  
transect T5 at 1339 (GMT) on 11 November 2004)

T4\_11\_11\_1359.jpeg (depth-averaged current velocities across  
transect T4 at 1359 (GMT) on 11 November 2004)

T3\_11\_11\_1424.jpeg (depth-averaged current velocities across  
transect T3 at 1424 (GMT) on 11 November 2004)

T4\_11\_11\_1450.jpeg (depth-averaged current velocities across  
transect T4 at 1450 (GMT) on 11 November 2004)

T5\_11\_11\_1514.jpeg (depth-averaged current velocities across  
transect T5 at 1514 (GMT) on 11 November 2004)

T4\_11\_11\_1528.jpeg (depth-averaged current velocities across  
transect T4 at 1528 (GMT) on 11 November 2004)

T3\_11\_11\_1545.jpeg (depth-averaged current velocities across  
transect T3 at 1545 (GMT) on 11 November 2004)

T5\_11\_11\_1616.jpeg (depth-averaged current velocities across  
transect T5 at 1616 (GMT) on 11 November 2004)

T4\_11\_11\_1632.jpeg (depth-averaged current velocities across  
transect T4 at 1632 (GMT) on 11 November 2004)

T3\_11\_11\_1649.jpeg (depth-averaged current velocities across  
transect T3 at 1649 (GMT) on 11 November 2004)

T5\_11\_11\_1721.jpeg (depth-averaged current velocities across  
transect T5 at 1721 (GMT) on 11 November 2004)

T4\_11\_11\_1736.jpeg (depth-averaged current velocities across  
transect T4 at 1736 (GMT) on 11 November 2004)

T3\_11\_11\_1748.jpeg (depth-averaged current velocities across  
transect T3 at 1748 (GMT) on 11 November 2004)

T5\_11\_11\_1822.jpeg (depth-averaged current velocities across  
transect T5 at 1822 (GMT) on 11 November 2004)

Table G1. (Continued)

**Current Transect Measurements (continued)**

T4\_11\_11\_1836.jpeg (depth-averaged current velocities across transect T4 at 1836 (GMT) on 11 November 2004)

T3\_11\_11\_1851.jpeg (depth-averaged current velocities across transect T3 at 1851 (GMT) on 11 November 2004)

T5\_11\_11\_1922.jpeg (depth-averaged current velocities across transect T5 at 1922 (GMT) on 11 November 2004)

T4\_11\_11\_1936.jpeg (depth-averaged current velocities across transect T4 at 1936 (GMT) on 11 November 2004)

T3\_11\_11\_1951.jpeg (depth-averaged current velocities across transect T3 at 1951 (GMT) on 11 November 2004)

T5\_11\_11\_2022.jpeg (depth-averaged current velocities across transect T5 at 2022 (GMT) on 11 November 2004)

T4\_11\_11\_2039.jpeg (depth-averaged current velocities across transect T4 at 2039 (GMT) on 11 November 2004)

T3\_11\_11\_2055.jpeg (depth-averaged current velocities across transect T3 at 2055 (GMT) on 11 November 2004)

T1\_2\_8\_1341.jpeg (depth-averaged current velocities across transect T1 at 1341 (GMT) on 8 February 2005)

T2\_2\_8\_1415.jpeg (depth-averaged current velocities across transect T2 at 1415 (GMT) on 8 February 2005)

T1\_2\_8\_1450.jpeg (depth-averaged current velocities across transect T1 at 1450 (GMT) on 8 February 2005)

T1\_2\_8\_1459.jpeg (depth-averaged current velocities across transect T1 at 1459 (GMT) on 8 February 2005)

T3\_2\_8\_1520.jpeg (depth-averaged current velocities across transect T3 at 1520 (GMT) on 8 February 2005)

T2\_2\_8\_1532.jpeg (depth-averaged current velocities across transect T2 at 1532 (GMT) on 8 February 2005)

T1\_2\_8\_1604.jpeg (depth-averaged current velocities across transect T1 at 1604 (GMT) on 8 February 2005)

T1\_2\_8\_1614.jpeg (depth-averaged current velocities across transect T1 at 1614 (GMT) on 8 February 2005)

T3\_2\_8\_1636.jpeg (depth-averaged current velocities across transect T3 at 1636 (GMT) on 8 February 2005)

T2\_2\_8\_1649.jpeg (depth-averaged current velocities across transect T2 at 1649 (GMT) on 8 February 2005)

T1\_2\_8\_1723.jpeg (depth-averaged current velocities across transect T1 at 1723 (GMT) on 8 February 2005)

T3\_2\_8\_1747.jpeg (depth-averaged current velocities across transect T3 at 1747 (GMT) on 8 February 2005)

T2\_2\_8\_1803.jpeg (depth-averaged current velocities across transect T2 at 1803 (GMT) on 8 February 2005)

(Sheet 4 of 7)

Table G1. (Continued)

**Current Transect Measurements (continued)**

T1\_2\_8\_1840.jpeg (depth-averaged current velocities across transect T1 at 1840 (GMT) on 8 February 2005)

T3\_2\_8\_1909.jpeg (depth-averaged current velocities across transect T3 at 1909 (GMT) on 8 February 2005)

T3\_2\_8\_2012.jpeg (depth-averaged current velocities across transect T3 at 2012 (GMT) on 8 February 2005)

T1\_2\_8\_2048.jpeg (depth-averaged current velocities across transect T1 at 2048 (GMT) on 8 February 2005)

**Data Files****Water-Level Measurements**

Readme.txt (Table H1)

TG1.txt (water levels measured from TG1)

TG2.txt (water levels measures from TG2)

TG3.txt (water levels measured from TG3)

TG3.txt (water levels measured from TG4)

NOAA.txt (water levels measured from the NOAA tide gage)

**Moored Current Measurements**

Readme.txt (Table H2)

CM2.txt (depth-averaged current velocities from CM2)

**Logan Airport Wind Measurements**

Readme.txt (Table H3)

Wind.txt (wind speed and direction measured at Logan Airport)

**Current Transect Measurements**

Readme.txt (Table H4)

T4\_11\_11\_1321.txt (depth-averaged current velocities across transect T4 at 1321 (GMT) on 11 November 2004)

T5\_11\_11\_1339.txt (depth-averaged current velocities across transect T5 at 1339 (GMT) on 11 November 2004)

T4\_11\_11\_1359.txt (depth-averaged current velocities across transect T4 at 1359 (GMT) on 11 November 2004)

T3\_11\_11\_1424.txt (depth-averaged current velocities across transect T3 at 1424 (GMT) on 11 November 2004)

T4\_11\_11\_1450.txt (depth-averaged current velocities across transect T4 at 1450 (GMT) on 11 November 2004)

T5\_11\_11\_1514.TXT (depth-averaged current velocities across transect T5 at 1514 (GMT) on 11 November 2004)

T4\_11\_11\_1528.txt (depth-averaged current velocities across transect T4 at 1528 (GMT) on 11 November 2004)

T3\_11\_11\_1545.txt (depth-averaged current velocities across transect T3 at 1545 (GMT) on 11 November 2004)

T5\_11\_11\_1616.txt (depth-averaged current velocities across transect T5 at 1616 (GMT) on 11 November 2004)

T4\_11\_11\_1632.txt (depth-averaged current velocities across transect T4 at 1632 (GMT) on 11 November 2004)

Table G1. (Continued)

**Current Transect Measurements (continued)**

T3\_11\_11\_1649.txt (depth-averaged current velocities across transect T3 at 1649 (GMT) on 11 November 2004)

T5\_11\_11\_1721.txt (depth-averaged current velocities across transect T5 at 1721 (GMT) on 11 November 2004)

T4\_11\_11\_1736.txt (depth-averaged current velocities across transect T4 at 1736 (GMT) on 11 November 2004)

T3\_11\_11\_1748.txt (depth-averaged current velocities across transect T3 at 1748 (GMT) on 11 November 2004)

T5\_11\_11\_1822.txt (depth-averaged current velocities across transect T5 at 1822 (GMT) on 11 November 2004)

T4\_11\_11\_1836.txt (depth-averaged current velocities across transect T4 at 1836 (GMT) on 11 November 2004)

T3\_11\_11\_1851.txt (depth-averaged current velocities across transect T3 at 1851 (GMT) on 11 November 2004)

T5\_11\_11\_1922.txt (depth-averaged current velocities across transect T5 at 1922 (GMT) on 11 November 2004)

T4\_11\_11\_1936.txt (depth-averaged current velocities across transect T4 at 1936 (GMT) on 11 November 2004)

T3\_11\_11\_1951.txt (depth-averaged current velocities across transect T3 at 1951 (GMT) on 11 November 2004)

T5\_11\_11\_2022.txt (depth-averaged current velocities across transect T5 at 2022 (GMT) on 11 November 2004)

T4\_11\_11\_2039.txt (depth-averaged current velocities across transect T4 at 2039 (GMT) on 11 November 2004)

T3\_11\_11\_2055.txt (depth-averaged current velocities across transect T3 at 2055 (GMT) on 11 November 2004)

T1\_2\_8\_1341.txt (depth-averaged current velocities across transect T1 at 1341 (GMT) on 8 February 2005)

T2\_2\_8\_1415.txt (depth-averaged current velocities across transect T2 at 1415 (GMT) on 8 February 2005)

T1\_2\_8\_1450.txt (depth-averaged current velocities across transect T1 at 1450 (GMT) on 8 February 2005)

T1\_2\_8\_1459.txt (depth-averaged current velocities across transect T1 at 1459 (GMT) on 8 February 2005)

T3\_2\_8\_1520.txt (depth-averaged current velocities across transect T3 at 1520 (GMT) on 8 February 2005)

T2\_2\_8\_1532.txt (depth-averaged current velocities across transect T2 at 1532 (GMT) on 8 February 2005)

T1\_2\_8\_1604.txt (depth-averaged current velocities across transect T1 at 1604 (GMT) on 8 February 2005)

T1\_2\_8\_1614.txt (depth-averaged current velocities across transect T1 at 1614 (GMT) on 8 February 2005)

(Sheet 6 of 7)

Table G1. (Concluded)

<b>Current Transect Measurements</b>	
	T3_2_8_1636.txt (depth-averaged current velocities across transect T3 at 1636 (GMT) on 8 February 2005)
	T2_2_8_1649.txt (depth-averaged current velocities across transect T2 at 1649 (GMT) on 8 February 2005)
	T1_2_8_1723.txt (depth-averaged current velocities across transect T1 at 1723 (GMT) on 8 February 2005)
	T3_2_8_1747.txt (depth-averaged current velocities across transect T3 at 1747 (GMT) on 8 February 2005)
	T2_2_8_1803.txt (depth-averaged current velocities across transect T2 at 1803 (GMT) on 8 February 2005)
	T1_2_8_1840.txt (depth-averaged current velocities across transect T1 at 1840 (GMT) on 8 February 2005)
	T3_2_8_1909.txt (depth-averaged current velocities across transect T3 at 1909 (GMT) on 8 February 2005)
	T3_2_8_2012.txt (depth-averaged current velocities across transect T3 at 2012 (GMT) on 8 February 2005)
	T1_2_8_2048.txt (depth-averaged current velocities across transect T1 at 2048 (GMT) on 8 February 2005)
<b>Project GIS</b>	
	Boston.apr (ArcView project file for displaying the vectorized current transect data)
<b>GIS files</b>	
	Vectorized data files and GIS geospatial information needed for the GIS project)
(Sheet 7 of 7)	

## Appendix H: Data File Formats

Table H1. Format of water-level measurement files on project DVD.

Water-level measurement files TG1.txt, TG2.txt, TG3.txt, TG4.txt, NOAA.txt		
Row	Field	Description
1	1	Instrument designation
	2	Geographic location description
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Hour of first data value in record (GMT)
	2	Minute of first data value in record (GMT)
	3	Month of first data value in record (GMT)
	4	Day of first data value in record (GMT)
	5	Year of first data value in record (GMT)
4 – end of record	1	Time in hours from first data value in record
	2	Water level in feet relative to the record mean for TG1, TG2, TG3, and TG4, and relative to mean lower low water (MLLW) for NOAA
<p>Example: First 6 rows of TG1.txt.</p> <pre> TG1 Chelsea Bridge 42.386556 71.039917 18 00 11 10 2004   0.00 5.27   0.10 5.09   0.20 4.84           </pre>		

Table H2. Format of moored current meter measurement file on project DVD.

Moored current meter measurements file CM2.txt		
Row	Field	Description
1	1	Instrument designation
	2	Geographic location description
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Hour of first data value in record (GMT)
	2	Minute of first data value in record (GMT)
	3	Month of first data value in record (GMT)
	4	Day of first data value in record (GMT)
	5	Year of first data value in record (GMT)
4	1	Time in hours from first data value in record
	2	Depth-averaged current speed in feet per second
	3	Depth-averaged direction current is going to in degrees true
<p>Example: First 6 rows of CM2.txt.</p> <pre> CM2 Near the seaward end of the navigation channel 42.363833 70.918000 14 21 11 10 2004   0.00 0.42 47   0.25 0.52 43   0.50 0.63 44 </pre>		

Table H3. Format of Logan Airport wind measurement file on project DVD.

Logan Airport wind measurements file Wind.txt		
Row	Field	Description
1	1	Month and day of measurement (GMT)
	2	Time of measurement (GMT)
	3	Wind speed in meters per second
	4	Direction the wind is blowing from in degrees true
<p>Example: First 6 rows of Wind.txt. Note that the first 6 rows have 4 invalid directions (i.e., 999) and 3 invalid speeds or no wind (i.e., 0.0).</p> <pre> 1110 1454 0.0 999 1110 1554 0.0 999 1110 1654 1.5 999 1110 1754 3.6 160 1110 1854 3.6 240 1110 1954 3.6 220 </pre>		

Table H4. Format of current transect measurement file on project DVD.

Current transect measurements files - name format: transect_month_day_time.txt Example: T5_11_11_1721.txt		
Row	Field	Description
1	1	Year of measurement in 2000 (i.e., either a 4 or a 5) (local)
	2	Month of measurement (local)
	3	Day of measurement (local)
	4	Hour of measurement (local)
	5	Minute of measurement (local)
	6	Second of measurement (local)
	7	Hundredth of a second of measurement (local)
	8	Depth in feet
2	1	Latitude, degrees north
	2	Longitude, degrees west
3	1	Depth-averaged current speed in feet per second
	2	Depth-averaged direction current going to in degrees true
Example: First 6 rows of T5_11_11_1721.txt.		
<pre> 4 11 11 12 17 43 32 13.84 42.3381006 -71.0081996 0.36 302 4 11 11 12 17 49 71 14.09 42.3381592 -71.0081658 0.43 127 </pre>		

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14. ABSTRACT A field data collection program in Boston Harbor, MA, was conducted for the U.S. Army Engineer District, New England, during the late fall and winter of 2004/2005. The purpose of the program was to obtain data needed to validate a numerical hydrodynamic model (ADvanced CIRCulation (ADCIRC) model) of Boston Harbor and adjacent areas. The currents calculated by the verified model were input to a ship simulator used to assess the design of the Boston Harbor navigation improvement project. A total of four water-level recorders and two acoustic profiling current meters were deployed on 10 November 2004. The water-level recorders were located adjacent to a bridge between Chelsea and East Boston in Boston's inner harbor, at the seaward end of Boston North Channel, at Gallops Island, and at the Hull Yacht Club in Allerton Harbor. The current meters were located at the seaward end of Boston North Channel and near the location where Boston's main navigation channel enters the inner harbor. Data from these instruments were supplemented by tide data from a National Oceanic and Atmospheric Administration (NOAA) tide gage in the inner harbor, and NOAA wind measurements at Logan Airport. In addition, daylight current transect surveys using a downward looking acoustic profiling current meter attached to a survey vessel were conducted on 11 November 2004 and 8 February 2005. Five transect survey lines across the main navigation channel were surveyed. All instrumentation was recovered on 7 and 8 February 2005. <div style="text-align: right;">(Continued)</div>					
15. SUBJECT TERMS		Boston Harbor, MA		New England District	
Acoustic current meters		Boston Harbor Navigation Channel		Tide gages	
Advanced circulation model		Navigation improvement project		Water-level data	
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#### 14. ABSTRACT (concluded)

Maximum-measured ebb tidal currents in the harbor were 0.9 to 3.84 ft/sec. Maximum-measured flood currents were 0.77 to 3.61 ft/sec. In general, the ebb currents were stronger than the flood currents. The data from the current meter deployed at the seaward end of Boston North Channel were analyzed to evaluate the importance of the wind-driven and tide-induced residual currents. The results of the analysis were that combined, these currents are small (5 to 22 percent of the ebb currents and 6 to 26 percent of the flood currents) compared to the maximum-measured tidal currents within the harbor. The tide-induced residual current at the seaward end of the navigation channel was estimated to be 0.07 ft/sec. The technical literature shows that tide-induced residual currents within the harbor, in the vicinity of the navigation channel, are stronger than they are at that location, with speeds of about 0.33 ft/sec. The largest currents at the seaward end of the navigation channel resulting from the action of the wind during major storms were associated with outflow of the storm surge from within the harbor. The analyses showed that during a major storm in December 2004, the currents were 0.54 ft/sec toward 70 deg, and during one of the worst storms (in terms of wind speed) in recent history, which occurred in January 2005, they were 0.56 ft/sec toward 69 deg (both speeds include an estimated tide-induced residual vector of 0.07 ft/sec toward 90 deg). The maximum water-level range is defined as the largest change in elevation from high-water to the low-water immediately following, that was recorded at a gage location. The maximum water-level range includes wind effects, as well as the astronomical tide. The range was 13.9 ft at the bridge between Chelsea and East Boston, 13.5 ft at Gallops Island, 14.1 ft at the Hull Yacht Club, and 13.9 ft at the NOAA gage.